

MANUAL OF ANIMAL BIOLOGY

BAITSELL

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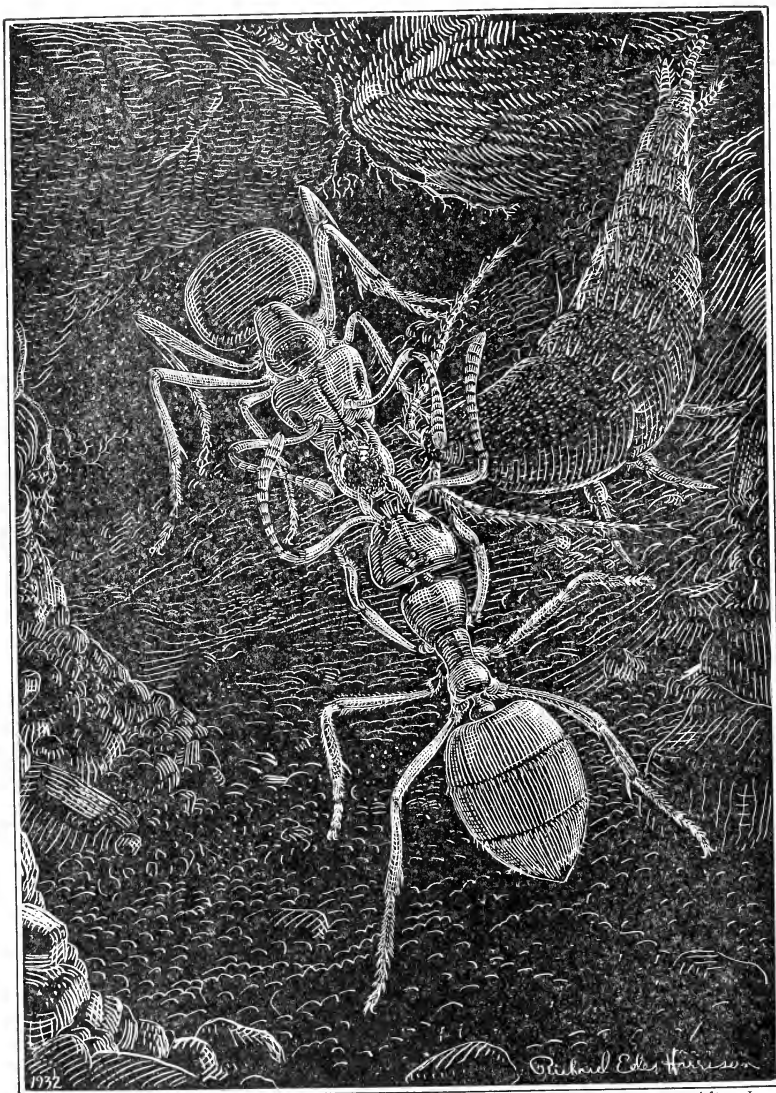
MANUAL OF ANIMAL BIOLOGY



THE MACMILLAN COMPANY
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ATLANTA • SAN FRANCISCO

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MELBOURNE

THE MACMILLAN COMPANY
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TORONTO



After Janet

ANTS FEEDING IN THEIR NEST
(For description of figure see page 137)

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MANUAL OF ANIMAL BIOLOGY

BY
GEORGE ALFRED BAITSELL
PROFESSOR OF BIOLOGY IN YALE UNIVERSITY

NEW YORK
THE MACMILLAN COMPANY
1932

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Published May, 1932.

SET UP AND ELECTROTYPED BY J. S. CUSHING CO.
PRINTED IN THE UNITED STATES OF AMERICA
BY BERWICK & SMITH CO.



PREFACE

IN this volume will be found descriptions of the structures and life processes, together with directions for laboratory study, of a number of animal types which have proved to be of outstanding value for those beginning the study of animal biology. In all of the descriptions a careful endeavor has been made to select the relevant facts and to give a direct and uniform presentation without unnecessary details or unimportant terms.

The general plan of this book and much of the contents are the same as in the *Manual of Biology*, Fourth Edition, which has been so favorably received in many laboratories, but there are certain important differences which should be noted. In the first place, the consideration of plant types is sufficient only to give an understanding of their basic importance in animal nutrition. This restriction of the plant material has permitted the inclusion of several additional animal types as well as the introduction of considerable new material throughout, but particularly in connection with vertebrate structure and function.

Secondly, in addition to the page and figure references which link it closely with the companion volume, *Animal Biology*, by Professor L. L. Woodruff, there will be found at the end of each chapter a series of page references to a number of other standard textbooks in animal biology or zoölogy and also to a few carefully chosen reference books for more detailed information; all of which it is hoped will add to the general adaptability for various types of zoölogical courses.

Finally, particular attention should be called to the series of full-page illustrations which, with two exceptions, were drawn for this *Manual* by Richard Edes Harrison. They are based whenever possible on the study of living animals and for the most part are habitat groups, definitely designed to stimulate the interest of the reader in the detailed study of the various types. It is a pleasure to acknowledge Mr. Harrison's ability both as a biologist and as an artist, as is evidenced by these figures. Mention should

also be made of the amphibian group (figure 10), drawn by Miss Lisbeth Krause of the Osborn Laboratory staff, which is of the same high quality.

It is a pleasure to have another opportunity to acknowledge the help received from my colleagues at Yale University, from Professor W. B. Unger of Dartmouth College, and, in particular, from Professor Woodruff, to whom I am also under great obligation for his critical reading of the complete proof. In connection with the new illustrations, especial mention should be made of the assistance given by Professors S. C. Ball, W. R. Coe, R. G. Harrison, A. Petrunkevitch, L. L. Woodruff, and Dr. T. C. Barnes of this laboratory; also by Professor R. S. Lull, Director of the Peabody Museum, and Professor G. R. Wieland, of the Department of Botany, Yale University. Grateful acknowledgment is also given to the American Museum of Natural History of New York for assistance given to Mr. Harrison in connection with the habitat groups shown in figure 4 and figure 9; and to the Macmillan Company for their permission to include figure 12 from Needham's *Chemical Embryology*. Once more I am indebted to the Macmillan Company for the interest shown in this work and the splendid coöperation given which has made possible its prompt publication.

GEORGE A. BAITSELL.

OSBORN ZOÖLOGICAL LABORATORY
YALE UNIVERSITY
April, 1932

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PART I
DESCRIPTIVE

NOTE

The references in this *Manual* designated by B or undesignated refer to material in this volume. Those designated by W refer to material in the *Animal Biology* by L. L. Woodruff (Macmillan).

At the end of each chapter, references will be found to certain other standard texts in Zoölogy.



MANUAL OF ANIMAL BIOLOGY

I. PROTOPLASM

THE world in which we live contains a great many diverse types of living organisms which are known to us either as PLANTS or as ANIMALS. The study of all the phenomena of life, without regard to animal or plant origin, constitutes the science of BIOLOGY. ZOÖLOGY, or ANIMAL BIOLOGY, treats of living phenomena in so far as they are exhibited by animals, and the companion science of BOTANY, or PLANT BIOLOGY, occupies the same sphere in the plant kingdom.

Vital phenomena have their origin in a unique substance, known as PROTOPLASM, which is the basic material — the life stuff — constituting the bodies of all living organisms. It should also be emphasized at once that protoplasm is never found apart from the complete organized unit, that is, the individual plant or animal. An additional fact of fundamental importance is revealed by the microscopic examination of the tissues from any organism, namely, that protoplasm does not occur in large unorganized masses, but always in the form of microscopic units, termed CELLS, which are the ultimate structural and functional units of life.

A. CELLULAR ORGANIZATION

In the lowest forms of life the entire organism consists of a single cell which is able efficiently to perform all the processes essential to life. Such organisms are termed UNICELLULAR. In the higher types of living organisms, the body is composed of an almost inconceivable number of cells, groups of which are specialized for the various necessary functions in the life of the individual, such as nutrition, respiration, reproduction, etc. Such organisms are termed MULTICELLULAR, and include all the familiar forms of plants and animals.

A simple way to get an idea of the CELLULAR ORGANIZATION, which is characteristic of protoplasm, is to make a microscopic examination of a small piece of EPIDERMIS shed from the skin of the Frog. A thin layer of this material forms the outer surface of the skin all over the body. Such an examination will reveal the fact that the skin epidermis is not a homogeneous body of material, but, on the contrary, is an aggregate of great numbers of microscopic cells which, generally, are in contact with adjacent cells on all sides, thus forming a TISSUE. A similar examination of the epidermis from our own bodies or of the various tissues from any multicellular organism shows that they are built up from cellular units having the same general organization as those present in the epidermis of the Frog. (W. f. 2.)

A clear conception should be obtained of the fact that cells are solids, having length, breadth, and thickness, and not merely flat surfaces as they appear to be when a section of some tissue is examined under the microscope. The three dimensions of cells can be obtained from a study of some suitable tissue in which the cells are regularly arranged and which has been sectioned in two different planes which lie perpendicular to each other. Thus we may compare the shape of the cells as seen in a longitudinal section with that found in a transverse, or vertical, section. In one of these planes, the cells will be seen from a side view, which will give the length and breadth, while in the other plane, an end view will be seen from which the third dimension, thickness, may be obtained. (W. f. 5.)

A crude comparison is sometimes made between the cells which compose a living organism and the bricks as the structural elements in a building. From the structural standpoint the analogy is, perhaps, a fitting one, as is well-shown by the microscopic examination of various tissues indicated above. From another, and much more important viewpoint, however, the comparison is meaningless, for the bricks are inert masses of lifeless clay which are unable to play any part in the activities of the building of which each constitutes a structural unit, while, on the other hand, every one of the cells which go to make up the living organism is a dynamic, protoplasmic unit endowed with the principle we call life and continually performing its share of the many functions which are essential to the maintenance of life in the organism.

B. THE STRUCTURE OF CELLS

1. *Cytoplasm*

The many different types of cells, although showing considerable variation in certain details, nevertheless exhibit a number of fundamental structural features which may now be noted. In the first place the protoplasm is differentiated into the **CYTOPLASM**, which constitutes the main mass of the cell body, and a much smaller spherical body, the **NUCLEUS**, which typically lies near the center of the cytoplasm. This differentiation of the cell protoplasm is regarded as basic for cell structure, as is shown by the usual definition that a "cell is a mass of protoplasm containing a nucleus." Cytoplasm and nucleus together are often termed the **PROTOPLAST**. In many of the unicellular animals the cytoplasm shows a definite division into a larger central mass, the **ENDOPLASM**, in which the nucleus is embedded, and an outer portion, the **ECTOPLASM**. (W. f. 7.)

The cytoplasm contains certain protoplasmic inclusions, such as **MITOCHONDRIA**, **GOLGI BODIES**, **PLASTIDS**, etc., which undoubtedly play very important rôles in the life processes of cells. Almost all of these bodies are still the subjects of extended research bearing upon their structure and functions. The plastids are of particular interest because a certain type, the **CHLOROPLASTIDS**, found in the green plant cells contain the basic food-building substance, **CHLOROPHYLL**, to be considered in detail later. Another important protoplasmic inclusion usually present in the cytoplasm is the **CENTROSOME** which is very active in cell division and, in fact, is generally regarded as the dynamic center for this fundamental process.

However, not all of the inclusions in the cytoplasm consist of living matter, for various non-living materials, collectively termed **METAPLASM**, are present. The metaplasm varies greatly in character and amount in different types of cells and in the same cell at different times. It consists of waste products and reserve food materials, and it may be in the form of water vacuoles, fat droplets, crystals, etc. Mature plant cells generally possess a large central cavity, the **CELL VACUOLE**, which is filled with a fluid, the **CELL SAP**, containing materials of importance in the nutrition of the cell. (W. f. 10.)

2. *Nucleus*

The protoplasm of the nucleus, which we may term **KARYOPLASM** in contradistinction to the surrounding cytoplasm, is enclosed in a definite **NUCLEAR MEMBRANE** except when the cell is undergoing reproduction by division. The structure of the karyoplasm is extraordinarily complex and varied. Typically a delicate network, or **LININ**, is found throughout the nucleus. The most prominent feature of the karyoplasm, however, is the **CHROMATIN** which derives its name from the fact that it stains very deeply with certain dyes. In a resting cell, the chromatin appears as a more or less granular material which may be condensed into one or more knots, the **KARYOSOMES**. In a dividing cell, the chromatin forms a long tangled thread, the **SPIREME**, which later breaks up into a definite number of bodies, the **CHROMOSOMES**. It is hard to overestimate the importance of the chromatin for there is a great abundance of evidence to show that it is the chief vehicle for the transmission of hereditary characters from one generation to another. Mention should also be made of a tiny, spherical body, the **NUCLEOLUS**, which is frequently present in a nucleus. Its function is quite obscure. (W. f. 10.)

3. *Cell Wall*

An outer limiting membrane of some type, which forms the cell boundary, is always present. In some types of cells this enclosing membrane consists only of a slightly modified region of the peripheral cytoplasm, known as the **PLASMA MEMBRANE**. Usually, however, there is also present a definite outer **CELL WALL**, of varying thickness, which is formed as a non-living secretion of the underlying cytoplasm so that the cytoplasm of the cell is doubly enclosed. In plant cells, the cell wall is particularly prominent and is largely composed of **CELLULOSE**, which is an extraordinarily abundant and important organic compound similar to starch in its chemical constitution; while in animals cells, the cell wall is usually of a protein nature. (W. fs. 7, 12.)

Whatever the exact structure and the degree of development of the plasma membranes and cell walls in various types of cells, the really essential fact is that they are all semi-permeable membranes, that is, they are of such a nature as to permit the necessary and continuous interchange of certain substances between a living cell

and its environment. The movements of materials through the cell boundaries are believed to be in accordance with well-established physical laws which govern the passage, or diffusion, of liquids and gases through various types of membranes.

4. *Physical Nature of Protoplasm*

Having considered the cellular organization of protoplasm as well as the main structural features of a typical cell, we are prepared to go a step further and indicate certain general facts bearing on the physical nature of protoplasm. As a matter of fact one can speak only in very general terms on this subject for our knowledge at present concerning the ultimate structural organization of protoplasm is limited. This is due to the fact that protoplasm cannot be subjected to intensive methods of analysis without destroying the primary object of the investigation, namely, the unique quality designated by the term LIFE. A chemical analysis of protoplasm after death shows that a very large percentage consists of water containing various chemical compounds. These compounds when separated into their elements show that about 99 per cent of the material present is derived from the following six elements: carbon, oxygen, hydrogen, nitrogen, calcium, and phosphorus. There is nothing peculiar about these elements. They are of common occurrence, and, therefore, it would seem that in living matter there must be a unique arrangement of these materials which is not found elsewhere in nature.

Observations on protoplasm show that it varies considerably in its physical appearance. Thus at one time it may appear as a clear, rather thick liquid while at another it appears as a gelatinous mass. This variation in the consistency of protoplasm, together with certain other characteristics, has led to the conclusion that it is of a COLLOIDAL nature. There are many types of non-living colloids known, all of which are characterized structurally by the presence of exceedingly minute particles — in many cases too small to be seen, even with the highest powers of the microscope — dispersed throughout a liquid medium. Variations in the relations between the particles and the liquid medium result in changes in the state of the substance from a liquid (SOL) to a solid (GEL), and this is apparently what takes place in protoplasm. As might be expected from the structural variations occurring during life, the appearance of protoplasmic material, which has been

killed and then prepared for intensive microscopic study by sectioning and staining, is not always the same. Accordingly various theories are held regarding the ultimate architectural details. (W. f. 9.)

C. THE LIFE PROCESSES OF CELLS

1. *Metabolism*

In the protoplasm of every living cell, various essential life processes are continually taking place. These processes involve uninterrupted adjustments and exchanges of materials between a cell and its environment. This continuous interplay is a feature of outstanding importance as indicated by Herbert Spencer's famous definition of life as "the continuous adjustment of internal relations to external relations." These basic intracellular life processes may be grouped under the term METABOLISM which in turn may be subdivided into a constructive phase (ANABOLISM) and a destructive phase (KATABOLISM).

The metabolic processes acquire their paramount importance from the fact that the maintenance of life requires the continuous expenditure of energy. This essential energy is released by intracellular, oxidative processes which result in the tearing down of various complex, unstable chemical compounds present in, or forming a part of, the protoplasm, together with the formation of new compounds of relatively low energy content, which are given off as excretions. The latter consist of nitrogenous wastes (*e.g.*, UREA), carbon dioxide, and water containing various inorganic salts in solution.

It should be noted at this point that these essential oxidative processes require a continual supply of oxygen from the environment and the continual release of carbon dioxide from the cell into the environment. This constitutes RESPIRATION — a function which persists in every cell throughout life and is a true measure of the extent of the life activities. Thus respiration is linked with nutrition in that it supplies a necessary substance — oxygen — to the cell, and it is also linked with excretion in that it removes a metabolic waste — carbon dioxide — from the cell.

It is clear that these energy-yielding processes are essentially destructive, or katabolic, in their nature and may be crudely compared to the means used to secure energy to run an automobile. In this case gasoline, which is a complex and unstable chemical

compound with a high potential energy content, is vaporized and mixed with air containing oxygen. An electric spark is used to upset the chemical equilibrium: a new alignment of the chemical components takes place with explosive violence by which a considerable proportion of the stored-up energy is released. In part this active, or kinetic, energy is utilized in moving the car, some is dissipated as heat, while at the same time various simpler compounds with greatly reduced energy content are formed which may be regarded as the excretory products.

It is, of course, apparent that the katabolic processes could not long continue in the cell protoplasm in the absence of the constructive anabolic processes which function in the replacement of the materials destroyed to obtain energy. Accordingly we find that certain foodstuffs, rich in potential energy, are taken into the cell and, as the result of the anabolic activities, are actually built up into the living protoplasm.

Three great classes of foods are recognized, namely, CARBOHYDRATES, FATS, and PROTEINS. The proteins are essential for cell nutrition because they always contain nitrogen and various other elements, all of which are necessary constituents of protoplasm, linked up with carbon, hydrogen, and oxygen. The carbohydrates and fats contain only carbon, hydrogen, and oxygen — in varying proportions — and furnish a source of energy which may be at once utilized or stored away for a later emergency, but, since they lack nitrogen and other elements, they cannot be used to repair protoplasmic waste. Also the cells of a living organism must have water, free oxygen, various inorganic salts, and minute but constant quantities of certain very complex organic compounds, known as VITAMINES, the exact nature of which, as well as the rôles they play in cell metabolism, being largely unknown at the present time. (W. pp. 21-25.)

2. *Photosynthesis*

The metabolic processes described above are believed to be essentially the same in plant and animal cells. However, in certain cells of green plants, an additional and all-important life process takes place. This process, which is known as PHOTOSYNTHESIS, is superimposed upon the underlying metabolic processes, and it is based upon the presence of the complex, greenish-colored compound, CHLOROPHYLL. This unique substance makes it possi-

ble for the green plant cell to utilize the energy of sunlight for the manufacture, or synthesis, of the essential foodstuffs from the simple inorganic materials which are abundantly present in the immediate environment of the plant. This process of photosynthetic food manufacture is fundamental for all life because, in the final analysis, all plant and all animal food is formed in that way. Animals eat plants directly or they eat other animals which have eaten plants.

The substances taken into the plant cell consist of CARBON DIOXIDE which is a gas composed of one part of carbon and two parts of oxygen, and WATER which is composed of two parts of hydrogen and one part of oxygen. Dissolved in the water are various inorganic salts, particularly nitrates, which, as will be seen, are necessary constituents of the more complex foods.

Chlorophyll uses the energy of sunlight to separate the carbon from the oxygen in the carbon dioxide and to combine the carbon thus secured with the hydrogen and oxygen of the water to form a type of SUGAR, or CARBOHYDRATE, which is the first food product of photosynthesis. The oxygen which was separated from the carbon is not utilized in photosynthesis but passes off as free oxygen, and it may be later used in respiration by plant and animal cells as a basis of their katabolic activities. These latter, it will be remembered, disintegrate the complex compounds present in the cells in order to secure energy for the essential life processes; carbon and oxygen again uniting to form carbon dioxide which passes off as an excretory product.

Sugar having been formed, it may be utilized at once by the plant protoplasm (*a*) to secure energy through oxidation, or (*b*) it may be changed to another carbohydrate, STARCH, and stored for later use, or (*c*) the proportion of oxygen present in either the sugar or starch may be decreased, and thereby the food material changed from a carbohydrate into a FAT which may also be stored, or, finally, (*d*) the carbohydrate may be built up into the more complex food material, PROTEIN, by the addition of nitrogen and other inorganic salts dissolved in the water taken into the plant cells. There is a question as to whether the protein formation occurs as a part of the photosynthetic action or whether it is a later process brought about in some other way.

PLANTS. Since, then, plants are of basic importance in supplying the nutritive requirements of animals, it will be well to present

a few important facts regarding them at this point. Plants are probably the most abundant of all living organisms. They range in size from microscopic, unicellular species to the giant Redwoods of California. Four major divisions, or phyla, of the Plant Kingdom are recognized, namely: (a) the THALLOPHYTA, which include (i) the ALGAE (*e.g.*, *Pleurococcus* and *Spirogyra*, noted below) and (ii) the so-called Colorless Plants, or FUNGI (*e.g.*, Bacteria, Yeast, and Molds, noted below), which are unique in that they are the only group of plants which lack chlorophyll; (b) the BRYOPHYTA, or Mosses; (c) the PTERIDOPHYTA, or Ferns; and (d) the SPERMATOPHYTA, or Flowering Plants, which include most of our common species. Three common forms of green plants may now be indicated.

Pleurococcus. This is a very common, unicellular Alga which forms a greenish covering on the bark of trees, on flower pots, and on many other surfaces where a suitable environment is provided. The greenish covering, when examined microscopically, is found to consist of great numbers of tiny cells, each of which, since it contains the basic food-forming substance, chlorophyll, is able to manufacture complex foodstuffs photosynthetically from the simple inorganic materials present in the immediate environment, and thus to carry on an independent existence. Here in this minute cell, then, although it lacks all the specialized structures of the higher plants, are concentrated all the characteristic and essential life processes of green plants, including photosynthesis. (W. pp. 30-34.)

Spirogyra. This is a simple type of multicellular Alga which is frequently found floating on the surface of stagnant fresh-water ponds, and is often referred to as the Pond Scum. *Spirogyra* consists of a variable number of long, tubular cells attached end to end to form a fine thread-like filament, which constitutes the entire plant body. The cells, although attached, are independent functional units, each one performing all the essential life processes just as is the case in *Pleurococcus*. The cells of *Spirogyra* are characterized structurally by a very large and beautiful, spiral chloroplastid which lies just under the cell wall embedded in a layer of cytoplasm, like a piece of green ribbon. There may be one or more of these chloroplastids in each cell, depending upon the particular species examined. Each chloroplastid contains not only the chlorophyll for photosynthetic food manufacture, but

also numerous, small spherical bodies, the PYRENOIDS, which function in the formation and storage of reserve starch. (B. p. 21.)

Elodea. This is a highly developed, water-living species belonging to the Flowering Plants. In a plant of this type the cells are specialized for various functions. The chlorophyll-bearing cells are largely centered in the leaves, which are to be regarded as highly specialized organs for the processes associated with food manufacture. The chloroplastids of *Elodea* are tiny disc-shaped bodies which lie embedded in the cytoplasm near the cell wall. The cytoplasm of *Elodea* exhibits a noteworthy flowing movement, which is considered later (p. 16), and the chloroplastids are carried along in the current.

COLORLESS PLANTS. It has been noted above that the Colorless Plants, or Fungi, which include a large number of species belonging to such well-known groups as the Bacteria, Yeasts, and Molds, are characterized by the absence of chlorophyll. They are unable, therefore, to satisfy their nutritive requirements through the synthesis of essential foodstuffs from the inorganic materials in their environment as are the Green Plants. The Fungi, like the animals, must have organic compounds which had their origin in photosynthesis. On the other hand there is a wide divergence in their nutritive requirements, and many fungus species find adequate food materials in compounds much less complex in their chemical nature than those required for animal nutrition. Because of this, the Fungi play an essential rôle in the cycle of elements in nature by utilizing various organic substances which are not suitable for the nutrition of either green plants or of animals. In such cases the constituent elements can then be again utilized in photosynthesis by the chlorophyll-bearing plants. Furthermore, the Fungi, in their quest for nutrients, attack the tissues of dead organisms — the process of decay — and in the end make available to the green plants the vast amounts of materials there present which would otherwise be lost. Three groups of Fungi may now be indicated. (W. pp. 37-45.)

Bacteria. There are some 1400 species of Bacteria known, all of which are microscopic in size, and, in addition, there are undoubtedly many other species which are too small to be seen even under the highest magnification of the microscope. Structurally the bacteria cell appears to be very simple, consisting of a bit of cytoplasm, in which a definite nucleus is not apparent, enclosed in a cell wall.

Three types of these unicellular Fungi are noted, namely, the spherical COCCI, the rod-shaped BACILLI, and the spiral SPIRILLA. The Bacteria and all Fungi absorb their food materials in soluble form through the cell wall. Enzymes are secreted in many instances which act upon solid nutrient materials and render them soluble. Certain noteworthy groups of Bacteria are (a) the Decay Bacteria, which are almost omnipresent, (b) the Nitrogen-fixing Bacteria, which live on the roots of various plants and are characterized by their ability to 'fix' the free nitrogen of the air and thus make it available for the use of green plants, (c) the Disease-producing, or Pathogenic, Bacteria, which attack the tissues of living plants and animals and cause many of our worst diseases.

Yeast. The Yeasts, like the Bacteria, are widely distributed, unicellular Fungi with very simple structural features. Each Yeast plant consists of a microscopic, egg-shaped cell with a well-defined cell wall and a poorly defined nucleus. Yeast finds a particularly favorable environment in fruit juices containing sugar and protein material in solution. The respiratory function of the Yeast cell centers in the disintegration of the sugar molecule with the resulting formation of alcohol and carbon dioxide, and this is accomplished by a characteristic enzyme, ZYMASE.

Molds. There are a whole host of filamentous fungus forms, the Molds, which attack and thrive on a great variety of materials. They are able, as in the case of the common Bread Mold, to secrete an enzyme which renders the foodstuffs soluble so that they can be taken into the organism. In some cases the plant body is an undivided, multinucleate mass of protoplasm, thus lacking a definite cellular organization. In other groups the plant body of the Mold is definitely multicellular.

3. *Growth and Reproduction*

It is evident from the earlier discussion that two antagonistic life processes are in synchronous operation in a living cell. On the one hand there is the tearing down of the complex compounds with the resultant liberation of energy and the formation of metabolic wastes; on the other, there is a rebuilding through the utilization of the incoming nutritive materials. If the katabolic processes are greater, the DEATH of the cell will eventually result. If the sum total of the anabolic processes are greater, the GROWTH of the cell will occur. The growth of a living organism is by the

unique method, known as **INTUSSUSCEPTION**, which is characterized by the intercalation of new material among the old. It is quite unlike the process of increase in size by **ACCRETION** in which the new material is deposited externally on the old, and which is exhibited in the inorganic world in crystal formation.

Attention should now be called to the fact that the size of any specific type of cell is quite definitely limited, so that when a cell has reached a certain size, growth stops. At this point, provided the dominance of the anabolic processes continues, another characteristic feature of protoplasm appears in that the cell has the ability to divide into two daughter cells. This constitutes **REPRODUCTION**, and the result is the formation of two cells each having the general characteristics of the parent cell. The inherent relations which, it is now apparent, exist between anabolism, growth, and reproduction will be emphasized later in the study of *Amoeba* and other Protozoa.

The reproduction of a cell always takes place following a complicated process known as **MITOTIC CELL DIVISION**, or **MITOSIS**, which involves profound nuclear changes. These result in the correct quantitative and qualitative division of the chromatin material in the nucleus of the dividing cell, and its equal distribution to the two daughter cells. Since, as noted previously, the chromatin is the chief vehicle for the transmission of hereditary characters, the necessity for an accurate division of the material is evident. (W. pp. 239-243.)

4. *Differentiation*

It has been noted above that organisms consist either of one cell or of many cells. Attention should be called at this point to the additional fact that all organisms from the lowest to the highest, including Man, begin life as a single cell — they are originally unicellular — and it is by the continued growth and repeated division of the original cell into two, four, eight, and finally into millions and millions of cells, which remain permanently attached, that the adult organisms are built up. This brings in another important factor, namely, **DIFFERENTIATION**, which means that groups of cells become structurally modified, or differentiated, to perform a certain task, or function, for the organism as a whole so that in the higher multicellular organisms, or **METAZOA**, as they are termed, there is a **DIVISION OF LABOR** between different kinds of

cells. For instance, in an animal, the cells lining certain regions of the alimentary canal are differentiated for the digestion and absorption of food. They are not concerned with nor would they find it possible to function, for example, in hearing.

5. *Irritability and Adaptation*

Inasmuch as metabolism is a fundamental feature of protoplasm, it follows that organisms must have an environment which supplies the necessary materials together with favorable conditions for the continuous and successful operation of all these essential life processes. If an environment is too hot or too cold or too dry, metabolism may be hindered or entirely stopped. If water, oxygen, proteins, and other necessary materials are not in adequate supply, death results. In this connection another unique feature of protoplasm should be emphasized, namely, **IRRITABILITY**, by which is meant that living matter responds to its environment and is able thereby to determine whether or not the situation is advantageous or detrimental. In the higher animals, a differentiated **NERVOUS SYSTEM** is developed which is equipped to receive the external stimuli, translate them, and then to incite the proper coördinated response, or adaptation, on the part of the organism. Thus a continuous and exquisite adjustment is maintained between the organism and its environment. Furthermore, protoplasm possesses a certain amount of plasticity with regard to the surrounding conditions which we may call **ADAPTATION**. That is to say, protoplasm can adjust or adapt its metabolic processes to various environmental factors, such as temperature, so long as certain limits are not passed. Thus, for example, in a Frog, the life processes exhibit their highest rate of activity in the spring and summer when the temperature conditions are favorable. During the winter season when the environmental conditions are unfavorable the life processes are reduced to a minimum — the animal adapts itself to the situation and hibernates.

6. *Movement*

In the first place it should be noted that the power of movement, which is commonly associated with living organisms, is not peculiar to protoplasm. It is apparently inherent in all types of matter, and if we were able to examine the ultimate structure of a piece of metal or any other inanimate or animate material, a field of con-

tinuous and intense activity undoubtedly would be revealed. An indication of this is to be seen in the physical phenomenon known as BROWNIAN MOVEMENT. This occurs, for example, when a finely ground, insoluble substance is placed in water. A microscopic examination reveals a continuous, spontaneous movement of the particles, which is believed to be the expression of the activity of the ultramicroscopic molecules in the liquid.

Although, then, basically, this phenomenon cannot be regarded as a unique feature of living organisms, visible spontaneous movement is, nevertheless, the most striking and readily recognized indicator of life. By means of it organisms are able to perform various life functions. Thus movement is closely associated with nutrition in many forms of life. If the food supply is scarce or other environmental factors are unsuitable, many types of organisms are so equipped that they can move to a more favorable region. Indeed movement is vitally important in almost every phase of life; a fact that can probably be shown to the best advantage by noting a few representative types of protoplasmic movement.

FLOWING MOVEMENT. In many types of plant and animal cells a flowing, or streaming, of the protoplasm is easily observed under the microscope. In a unicellular form like the *Amoeba* where the protoplasm is not enclosed in a rigid cell wall, the direction and extent of the protoplasmic flow is irregular and depends largely upon the environmental factors. In higher types of cells with more or less rigid cell walls a regular streaming, or CYCLOSIS, of the enclosed cytoplasm occurs. This can be seen to good advantage in a unicellular animal like *Paramecium*. An especially good example is to be seen in the leaf cells of the fresh-water plant *Elodea*. In an active cell, a microscopic examination will show that the disc-shaped chloroplastids are moving around and around just inside the cell wall. This is due to the streaming of the cytoplasm in which the chloroplastids are embedded. Finally, it is probable that a definite and regular protoplasmic streaming occurs as a necessary feature in cell division. It has been found possible to detect a protoplasmic flow during this period. (W. fs. 11, 27.)

CILIARY MOVEMENT. Many types of cells possess CILIA. These are extremely fine, protoplasmic filaments which project from the cell surface. They exhibit a beautiful, coördinated lashing movement which, in the unicellular forms, serves to propel the organism

through the water and to aid in securing food. In higher organisms ciliated cells line various ducts and bring about the movements of fluids through them. (W. fs. 7, *E*; 27.)

MUSCULAR MOVEMENT. In the higher animals, the power of visible movement is centered in the contractile muscle tissue which is differentiated for this purpose. Muscle tissue is composed of highly specialized cells which act in unison when stimulated, and thus bring about a movement of the muscle as a whole. In the final analysis, however, it is the cytoplasmic movement in each muscle cell which brings about the mass movement of the entire muscle. (W. f. 7, *B*; 32, *E*.)

7. Summary

In summarizing, we find that life requires the constant expenditure of energy. This is obtained by the destructive oxidative process of katabolism. To balance this and also provide an excess of material for growth, there is the constructive process of anabolism in which food formed by photosynthesis is supplied. The sum total of these processes, or metabolism, involves the essential life processes of nutrition, respiration, excretion, growth, reproduction, and adaptation; all of which, in the final analysis, are centered in the cell as the fundamental structural and functional unit of every living organism.

In the following pages, descriptions are given of the structure and life processes of representative types of animals ranging from the comparatively simple, unicellular forms through various grades of multicellular complexity until the climax is attained in the Vertebrate animals. In considering these examples selected from the panorama of animal life, it is of primary importance for the student of biology to gain a clear conception as to how each organism, with its own peculiar structural and physiological problems, is able to perform the metabolic processes which are characteristic of, and essential to, all life.

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II. AMOEBA

AMOEBA is a particularly interesting and important type for biological study because it is one of the most primitive and simple living organisms known. It is a unicellular animal, and its structure is such that, with the aid of the microscope, it is possible to observe and study a tiny bit of that unique living substance, protoplasm, stripped of all the complicating structural features which tend to obscure it in the higher forms of life. Although practically devoid of structural differentiation, an Amoeba is able to carry on all the essential life processes with great success and efficiency. In the final analysis, therefore, this tiny animal cannot be regarded as being essentially simple in its ultimate structure. This is very apparent when we consider that the minute drop of protoplasm, which constitutes the Amoeba, is not only the vehicle but also the primary directing force for an amazing array of complicated processes which are necessary for life.

A. STRUCTURE OF AN AMOEBA

Under the high power of the microscope a living Amoeba is revealed as a tiny, irregular drop of a rather fluid material which is almost transparent. Continued observation soon shows that a streaming movement is continually occurring, and this results in a rapid change in the shape of the animal. In its very simple form, the Amoeba lacks one of the parts which, as has been noted in the previous chapter, is a usual feature of cell structure, namely, a definite cell wall. The protoplasm, however, is differentiated into the cytoplasm and nucleus which constitute the essential parts of cellular structure in all organisms. Furthermore, the cytoplasm of an Amoeba consists of a thin outer layer of **ECTOPLASM**, which serves as a simple type of protective layer, and an inner region of **ENDOPLASM** which constitutes the bulk of the animal.

The ectoplasm shows a clear, homogeneous structure and, in an active specimen, may be described as a rather viscous, trans-

parent liquid. It slowly flows in various directions, depending largely upon the environment. This movement results in the formation of irregularly shaped, protoplasmic projections, known as PSEUDOPODIA.¹ It is by means of the flowing movement, with the consequent formation of pseudopodia, that the animal moves. A movement of this type, as has been previously noted (B. p. 16), is known as amoeboid movement. The exact nature of amoeboid movement is not fully established, even though it has been the subject of a large amount of research work. (B. f. 1 : W. fs. 6, 13.)

The endoplasm, in comparison with the ectoplasm, is not so viscid a substance and it has a tendency to flow more readily. Observations on living Amoebae show, however, that in the formation of pseudopodia the flowing movement appears first in the ectoplasm, and later the endoplasm rapidly streams into the ectoplasmic region where the pseudopodium is being formed. The endoplasm is less transparent than the ectoplasm, and a microscopic study with the proper type of illumination shows clearly that it is not a homogeneous material. It is generally believed that the endoplasm consists of a basic ground substance in which innumerable, ultramicroscopic particles are suspended. In addition to these particles, which apparently form a fundamental constituent of the endoplasm, it will be found that there are also many particles of various kinds, shapes, and sizes present which are sufficiently large to be easily observed under the microscope. For the most part these are transient, non-living, metaplasmic materials, such as undigested particles of food, indigestible refuse, etc., which have not been expelled.

The endoplasm contains a number of other structures, the most important being the NUCLEUS, which is an essential part of every cell. It is probably the directing center for all the life processes. There is also a single CONTRACTILE VACUOLE which collects and expels the liquid and, possibly, gaseous wastes resulting from the breaking down of living material, as well as the excess water taken in with food. Numerous GASTRIC VACUOLES are present in which the particles of food that have been taken into the animal are being digested. The gastric vacuoles are temporary structures; the number present in an Amoeba at any time depending upon the amount of food material which is undergoing digestion.

¹ Singular, pseudopodium.

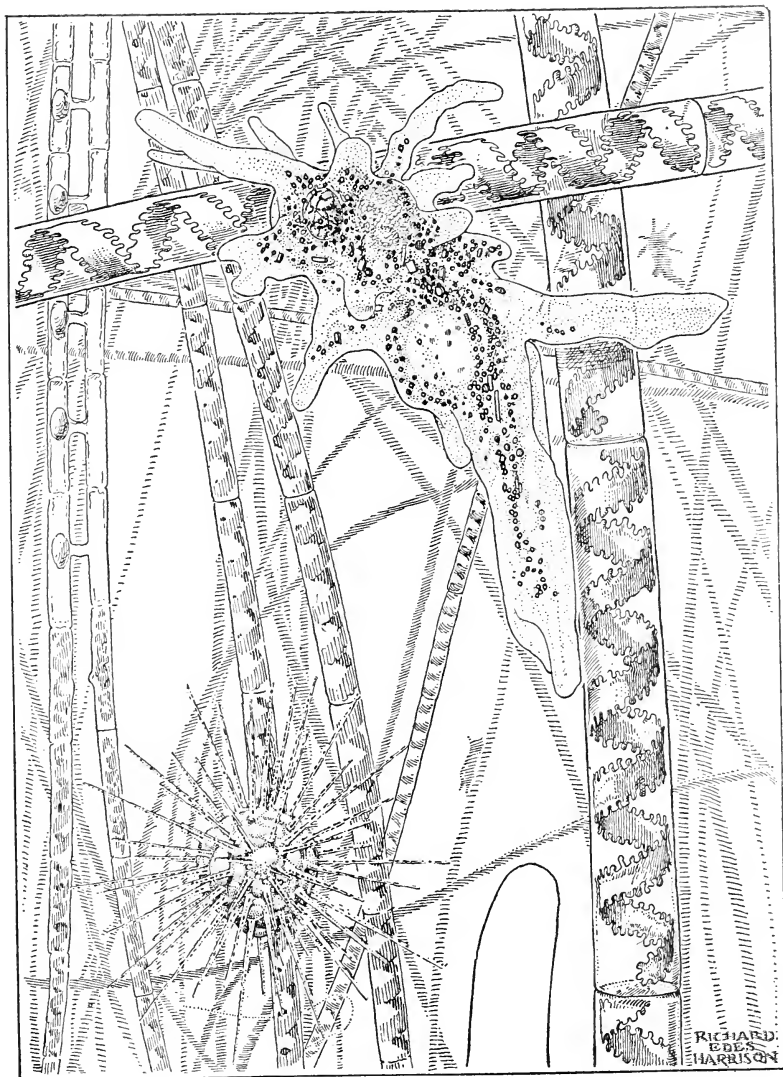


FIGURE 1

This figure, which was drawn from life, at a magnification of about 500 diameters, portrays a large specimen of the primitive, unicellular animal, *Amoeba*, moving along filaments of the common, green, water-living plant, *Spirogyra*. At the time the figure was drawn, the animal was moving downward along the vertical strand at the right of the figure as is indicated by the large, protruding pseudopodium. At the lower left, a related species, the beautiful Sun-animalcule, *Actinophrys*, is shown.

When it comes to the determination of the exact physical structure of protoplasm, whether it be from an Amoeba or from a Man, the problem becomes very difficult — in fact, so difficult that the solution is not apparent at the present time, even though it has been, and still is, the subject of a great amount of investigation by some of the ablest scientists. Scientific investigation with a view to determining the exact details of protoplasmic structure, as has been noted in the preceding chapter, is definitely limited by the fact that protoplasm cannot be subjected to intensive analytical methods without thereby destroying the primary object of the investigation, namely, the quality we call life. The dead material, which was formerly protoplasm, can, of course, be subjected to intensive analysis, but such studies have not so far revealed the basic secrets of protoplasmic structure.

B. LIFE PROCESSES OF AN AMOEBA

1. *Nutrition*

One of the fundamental characteristics of living organisms is the power to take in certain materials from the outside environment and either use them at once to supply energy for the life processes, or convert them into the actual living protoplasm of the body. The nutrition of an animal is designated as **HOLOZOIC**, and it involves destructive chemical processes in which various types of complex foodstuffs are broken down, and the resulting materials utilized in the various ways necessary either for the nourishment of the protoplasm or for securing energy for the essential life processes. The Amoeba exhibits a typical holozoic type of nutrition, and this animal has the power to carry on this process in essentially the same way as do the highest types of animal organisms, the only difference being that the single-celled animal, lacking the highly developed nutritive systems of the higher forms, does the work with much simpler apparatus. The holozoic nutrition of animals involves several stages, namely, the capture and ingestion of food, its digestion and assimilation, and, finally, the egestion of the indigestible refuse. These various steps in the nutrition of Amoeba may next be considered.

In the normal environment of the Amoeba there are materials of various kinds which the animal is able to utilize as food. Among these may be noted unicellular plants, such as the Bacteria and

Diatoms, filamentous Algae, other forms of Protozoa, and organic débris of many kinds. The Amoeba has only one method for securing all types of food material. This consists in moving towards the food particle and then gradually surrounding it by means of the pseudopodia. When the peripheral protoplasm comes into contact with a food particle, the process of ingestion begins at once. All regions of the ectoplasm of the Amoeba can perform this combined process of capture and ingestion. Apparently it is the chance contact which determines the particular region of the ectoplasm which is to act as the temporary organ for capturing a particular food particle or living organism, and also as the temporary mouth for engulfing it.

An Amoeba, of course, comes into contact with many particles of inorganic material, such as grains of sand, which cannot be utilized as food. It can generally be shown in such cases that the ectoplasm of the Amoeba differentiates between the materials which are suitable for food and other materials which cannot be so used. Thus, when an Amoeba comes into contact with a grain of sand, instead of engulfing it, the flowing movement and pseudopod formation in that direction ceases, and a movement is initiated in another direction, which avoids the undesirable material.

A food particle having been ingested by the ectoplasm next passes into the endoplasm, becomes surrounded by a small amount of fluid taken in with it, and constitutes a gastric vacuole in which DIGESTION takes place. The portion of endoplasm which surrounds the food material apparently becomes temporarily specialized for the work of digestion, and is able to secrete certain chemical substances, known as ENZYMES, which are believed to be of the same nature as those secreted in higher forms of animals by the glands in the walls of the alimentary canal. It is these enzymes which digest the food. Digestion, in all forms of organisms, may be defined as a process whereby the complex food materials are chemically changed so that they can be absorbed and assimilated by the cells, and thus made available for the protoplasm. This is just what happens to the food in the gastric vacuoles of an Amoeba. (W. f. 13.)

The process of assimilation of the digested material in Amoeba and in other unicellular forms is a comparatively simple one, for the food as it is digested in the gastric vacuole passes directly into the surrounding endoplasm and is at once available for energy or

for the construction of additional protoplasm. In practically all kinds of food a certain amount of indigestible material is taken into the body, and this must be eliminated. Such material has never been a part of the organism: it is only a temporary inclusion. The process of elimination of such material is known as *EGESTION* and is to be distinguished from the process of *EXCRETION*. The latter, as we have seen in the previous chapter, is concerned with getting rid of waste materials from substances that have actually played a part in the life of the organism. In the *Amoeba* there is no specialized structure for egesting the refuse from digestion. These wastes leave the animal through a temporary opening in the ectoplasm which forms at the spot which happens to be nearest to the gastric vacuole at the time digestion is completed.

2. *Respiration*

Respiratory activities — involving the intake of oxygen which is necessary for the metabolic processes, and the outgo of carbon dioxide which has been formed as a result of the destructive metabolic processes — are present in all organisms. Respiration may be regarded as a double process; on the one hand, the supplying of oxygen, which is a phase of nutrition, and on the other hand, the elimination of carbon dioxide, which is a phase of excretion. In the *Amoeba*, the entire surface of the animal serves as a medium through which this essential interchange of gases takes place. (W. f. 13.)

3. *Excretion*

The process of nutrition in *Amoeba*, considered above, results in supplying food materials to the animal, which are utilized either as a source of immediate energy, for repair, or for the growth of the animal by intussusception. So long as there is life, the protoplasm is continually being torn down, and, if life is to exist, it must be replaced just as continually by the assimilation of food material. The waste products, resulting from the destruction of the complex compounds in the protoplasm, consist chiefly of carbon dioxide, water with various inorganic salts in solution, and urea; the latter containing nitrogenous materials.

The nitrogenous wastes of *Amoeba* are excreted through the surface ectoplasm to some extent and also by means of a specialized structure, the contractile vacuole, into which the wastes from the

cytoplasm continually drain. As a result the vacuole enlarges. When a certain size is reached, the surrounding endoplasm contracts, and the wastes are forced out of the animal into the surrounding liquid environment through whatever portion of the ectoplasm happens to be nearest to the contractile vacuole at the time. By this contraction the vacuole is temporarily eliminated, but in a few moments the waste materials will again be present in a sufficient quantity to bring about a reappearance of the vacuole. A little later, the contractile vacuole having again attained the maximum size, a contraction takes place with a consequent expulsion of the liquid contents as before described. It is probable that this structure also functions in the removal of carbon dioxide.

4. *Reproduction*

When the food supply of an Amoeba is plentiful, so that the animal can ingest, digest, and assimilate food material in such an amount that the katabolic wastes are more than met, growth results. If this process of growth were able to continue indefinitely, an Amoeba of enormous size would soon develop. For some reason, however, Amoebae and other animals are limited, although there is some variation, to a certain maximum size which is characteristic of the particular species. When this limit is reached in an Amoeba, the unicellular animal divides by mitosis into two separate individuals, each of which when first formed is one-half the size of the parent. This method of reproduction in the unicellular forms is known as BINARY FISSION. The two daughter cells begin at once to assimilate food material in sufficient quantities to cause growth, and in a few hours each has attained the normal size. Reproduction by division may again take place, so that within the space of a few hours four independent Amoebae will thus have arisen from the original parent animal. (W. f. 3.)

If the environmental conditions continue to be favorable, there will be thousands of Amoebae in the course of a few days. The process of growth and reproduction could apparently continue, if the food supply held out and there were no other inhibiting environmental influences, until the earth was covered with a mass of amoebic protoplasm. It is a question, however, whether any protozoan cell can continue to divide indefinitely without the occurrence at certain intervals of some type of reorganization of the nuclear material, such as ENDOMIXIS in Paramecium. (B. p. 44.)

5. *Adaptation*

An Amoeba has the power of adapting itself to its environment in response to various kinds of stimuli which it receives. The protoplasm of which it is composed may be aroused or irritated by a number of external factors such as light, temperature, electricity, chemical stimuli, and contact. Any part of the ectoplasm of Amoeba is able to receive these stimuli and to respond to them: it is all irritable material. In higher forms of animals a specialized irritable tissue, the nerve tissue, is present, which is connected with, and forms, the essential part of various types of sense organs adapted for receiving different kinds of external stimuli.

The capture of food and the rejection of unsuitable materials by an Amoeba, which have been noted above, may be taken as examples of the ability of the ectoplasm of this animal to receive and be influenced by external stimuli. It is probable that food is secured in two ways: first, by the stimulus received through a chance contact with a food particle and, second, as a result of a chemical stimulus received from a distance. There is some evidence to show that the Amoeba and certain other species of Protozoa have the ability to 'sense' food at a distance and then move more or less directly toward it.

C. GENERAL FACTS OF IMPORTANCE

CLASSIFICATION. In beginning our study of representative animal forms which are of interest and importance from the general biological standpoint, it will be helpful to understand certain features of the systematic arrangement, or **CLASSIFICATION**, by which all organisms are placed in groups in accordance with what appears to be their true relationships as determined by all the available data. For efficient and systematic work in any field it is always necessary to arrange, or classify, the particular objects under consideration, whether they be living organisms or books in a library. The system of classification necessarily becomes more detailed and complex as the number of objects differing from each other increases. If there is only one point of divergence, then obviously only two groups are necessary, for all the objects could be classified in one or the other group. (W. pp. 46-47.)

In considering the animal kingdom we find that it is commonly divided into thirteen primary groups, each of which is known as

a PHYLUM. Every known animal is placed in one of these phyla. Thus the most primitive forms of animal life, including all the unicellular forms such as Amoeba, are placed in the first phylum, which is known as the PROTOZOA. Because of the great numbers of animals and their many points of divergence it is necessary to subdivide the phyla into many smaller divisions, the exact number of these divisions in any phylum depending upon the number of diverging organisms to be considered. (W. pp. 457-459.)

Considering the phylum Protozoa, there are four primary divisions, termed CLASSES. Amoeba and related forms which possess pseudopodia are put in the first class, the SARCODINA, which is again split into two subclasses. Amoeba belongs to the subclass RHIZOPODA, which are creeping forms as distinguished from the subclass ACTINOPODA, which are floating forms. Further subdivision can be made through ORDER, FAMILY, GENUS, and, finally, SPECIES. Animals belonging to a particular species conform very closely in their characteristics, but still show slight individual variations.

In naming an animal or plant the BINOMIAL SYSTEM OF NOMENCLATURE is used. The term binomial means that two names are employed which are those of the genus and the species. Thus in the case of Amoeba, the scientific name for the common species studied is *Amoeba proteus*, in which *Amoeba* is, of course, the name of the genus and *proteus* the name of the species. In many cases where exact scientific data are not involved it is customary, just as in this chapter, to omit the name of the species in referring to an organism.

OTHER NOTEWORTHY TYPES OF SARCODINA. There are a number of common species of Sarcodina which, unlike Amoeba, possess a shell. Thus Diffugia has a beautiful, cone-shaped shell which has been made by cementing bits of sand together. Another type of shell is found in forms like Arcella or in the Foraminifera which are formed as a secretion by the peripheral ectoplasm. The chemical composition of the shells varies greatly in the different groups. Great chalk deposits, which are of economic importance, have been formed in the past ages by the gradual accumulation of shells from the marine forms, particularly the Foraminifera. The Sun-animalcule, *Actinophrys*, shown on page 21, is a beautiful, fresh-water form with many fine pseudopodia radiating from the spherical cell body. (W. fs. 19-21, 244.)

There are several species of Amoebae which are parasitic in the

digestive tract of Man and various domestic animals. By far the most important of these is *Entamoeba histolytica* which attacks and destroys the cells lining certain regions of the intestine in Man, thus producing the very serious and widespread disease known as AMOEBIC DYSENTERY. (W. f. 245.)

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III. EUGLENA

EUGLENA is a common example of a very small group of unicellular, animal-like organisms which possess chlorophyll — that remarkable energy-trapping and food-synthesizing agent which, as has been noted, is characteristic of green plants. The presence of chlorophyll is considered by some authorities to be a fundamental and decisive feature and they, therefore, regard *Euglena* as a plant and place it in close relationship to the unicellular Algae, such as *Pleurococcus*. Other authorities, notwithstanding the plant-like nutrition, regard *Euglena* and similar forms as Protozoa because their general structure is very similar to undeniably unicellular animals. In other words, they regard *Euglena* as an animal which in some way has acquired a plant-like type of nutrition. For the present, *Euglena* may be considered as a border-line, or transitional form showing a close relationship to the Protozoa in its general structure and to the green plants in its nutrition.

Thus it is evident that in certain of the lower forms of life, the characteristics, which serve unmistakably to differentiate higher plants and animals, disappear, so that it becomes impossible, when considering these border-line forms, to say definitely that they are either plant or animal. They partake of the characters of both kinds of organisms.

A. STRUCTURE OF EUGLENA

Several species of *Euglena* are known, all of which are microscopic in size. Structurally they show a somewhat higher type of organization than does the *Amoeba*. The outer surface of the body is covered by a delicate, striated cell wall which is formed as a secretion by the underlying ectoplasm. An active *Euglena* exhibits peculiar squirming, or **EUGLENOID MOVEMENTS**, during which the shape of the cell varies greatly, ranging from nearly spherical to a typical cigar-shape. These changes in shape are possibly due to the fact that the cell wall, or **PELLICLE**, is very thin and, therefore, does not possess sufficient rigidity to hold the rather

fluid ectoplasm in a constant shape. The cell wall, however, is sufficient to maintain a regular body outline so that protruding pseudopodia are not formed as in the *Amoeba*. (B. p. 35.)

Projecting from the somewhat blunt anterior end of *Euglena* is a delicate, vibratile filament, or FLAGELLUM.¹ This structure arises from a number of very fine fibrils present in the ectoplasm near the anterior end of the body, which are united to form the flagellum. The flagellum is attached in a depression, or pit, in the ectoplasm. In some of the Protozoa this pit extends down into the endoplasm and serves as a passage for food particles. In *Euglena*, however, it apparently has nothing to do with the process of obtaining food, but serves as a canal for the passage of fluids from the contractile vacuole system. In an active individual the flagellum is continually vibrating with such great rapidity that it is difficult to see. It serves as an organ of locomotion and, as a result of its spiral movement, the organism is drawn ahead with considerable speed. (W. f. 22.)

The endoplasm of *Euglena*, which makes up the greater part of the animal, contains a number of interesting structures. At the anterior end, just back of the so-called gullet, is the contractile vacuole. This structure does not have the simplicity that characterized the single contractile vacuole of *Amoeba*. It consists of a large central reservoir which is believed to empty into the gullet. Around the edge of it are several tiny contractile vacuoles which discharge the liquid wastes into the central reservoir.

Situated close to the reservoir of the contractile vacuoles is a spherical body of great interest, known as the EYE SPOT, or STIGMA, which consists of a tiny bit of cytoplasm containing reddish-colored pigment (HEMATOCHROME). It is believed that the stigma is a primitive type of light-receiving apparatus since it is known that this region is sensitive to light rays. This enables *Euglena* to find the place in its environment which is best adapted for its photosynthetic nutritive processes. (W. f. 22.)

The chlorophyll in *Euglena* is contained in disc-shaped CHROMATOPHORES scattered through the endoplasm. PYRENIDS, which probably serve as starch-forming centers, can also be demonstrated in some individuals.

The comparatively large nucleus of *Euglena* lies embedded in the endoplasm, just posterior to the center of the animal.

¹ Plural, flagella.

B. LIFE PROCESSES OF EUGLENA

1. *Nutrition*

Possessing chlorophyll, *Euglena* is able to manufacture photosynthetically the complex foodstuffs necessary for the maintenance of life, just as is the case in the chlorophyll-bearing plant cell. It has also been shown that *Euglena*, when placed in an environment containing organic materials in solution, can nourish itself and thrive in the absence of sunlight. It is apparent in the latter condition that *Euglena* is able to make use of another type of nutrition, known as SAPROPHYTIC or SAPROZOIC — the exact term depending upon whether the organism is regarded as a plant or an animal — in which complex food materials in solution are taken through the cell wall by diffusion and assimilated.

There does not appear to be any evidence that *Euglena* ever receives any nutriment by the holozoic method of nutrition, such as was studied in *Amoeba*, in which solid particles of food are ingested and then acted upon by digestive ferments in order to render them soluble and capable of being assimilated.

2. *Respiration and Excretion*

It has been emphasized previously that the process of respiration is continuous in living organisms. There is no other way for them to secure the energy necessary to maintain vital processes. Respiration, however, may be obscured in an organism in which photosynthesis is occurring. Thus in daylight the chlorophyll in *Euglena* undoubtedly uses all the carbon dioxide produced by the katabolic processes in the cell and also takes in some additional from the environment, at the same time releasing the excess free oxygen formed by the photosynthetic processes. In the dark when photosynthesis stops, *Euglena* will necessarily give off the carbon dioxide and take in oxygen, just as in a typical animal cell like *Amoeba*. The elimination of the nitrogenous wastes from *Euglena* apparently occurs through the contractile vacuole apparatus and at the surface, as in *Amoeba*.

3. *Reproduction*

Under favorable environmental conditions, when a *Euglena* has reached a certain volume, reproduction by binary fission occurs, as noted in *Amoeba*, and two daughter cells result. The

cell body of *Euglena*, and other related forms, always divides longitudinally, beginning at the anterior end. Very shortly afterwards if the conditions are favorable, the daughter cells attain the structural organization and size of a typical *Euglena*. (W. f. 22, B.)

When the environmental conditions of *Euglena* are unfavorable, due to a lack of moisture or other factors, it has the power of ENCYSTING, a process which is quite common among many species of the unicellular organisms. The organism just previous to encystment becomes quiescent and soon assumes a spherical shape. The ectoplasm then secretes a resistant cyst wall which entirely encloses the cell. In this condition the dormant organism is able to withstand unfavorable environmental conditions. When the latter are again favorable the cyst wall is dissolved, and the *Euglena* once more assumes an active life. In many cases cyst formation is followed by reproduction, for during encystment one or more divisions of the cell body may occur, so that when the cyst wall is later dissolved, two or more individuals escape and begin an active, free-swimming existence. (W. f. 22, C.)

4. *Adaptation*

The stigma in *Euglena*, as has been stated above, is believed to be sensitive to light rays. Thus the organism is able to attain the particular location in any given environment which is best adapted for carrying on the photosynthetic processes. In a culture of *Euglena* it will be found, for example, that the individuals, in general, move toward the source of light. However, direct sunlight does not represent the best condition, and may even be fatal. If, therefore, one side of the culture is dark and the other side is in the direct sunlight, it will be found that the organisms tend to congregate in an intermediate zone between the two extremes. This particular region is the one with optimum conditions for photosynthesis. A response to light by an organism is spoken of as PHOTOTROPISM. *Euglena*, when it moves toward the light, is said to be positively phototropic, and when it moves away from light of high intensity, to be negatively phototropic.

The phenomenon of encystment, noted above, may be regarded as an adaptive measure which enables *Euglena* to survive unfavorable environmental conditions. It is of common occurrence among unicellular organisms.

C. GENERAL FACTS OF IMPORTANCE

RELATED SPECIES. *Euglena viridis* belongs to the protozoan class Mastigophora which, as the name indicates, is characterized by the presence of one or more whip-like, cytoplasmic filaments, the flagella. The Flagellates, as this group is more commonly termed, may be divided into the animal-like forms, such as the Trypanosomes some of which live in the blood of Man, and the plant-like forms, such as Euglena. Three common types of Flagellates are shown on page 35.

As a group the Mastigophora present several important problems. One of the most interesting of these is the question of the exact relationship of certain species. For example, a genus like Mastigamoeba which has the general structure and appearance of an Amoeba, but possesses a flagellum. There are also many colonial types among the Flagellates, which reach their culmination in Volvox, which is considered in the next chapter. Finally, many examples can be found of Flagellates which parasitize higher animals, including Man. These parasitic species may be divided into the blood dwellers, or Hemoflagellates, and the intestinal dwellers. The most important types are found among the Hemoflagellates, such as the Trypanosomes, which are the cause of the deadly Sleeping Sickness of the tropics. (W. fs. 29, 30, 224.)

Finally, it should be noted that the very important blood-dwelling Malarial Parasite does not belong to the Mastigophora, but to a separate class, the Sporozoa. (W. f. 223.)

TEXTBOOK REFERENCES

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IV. VOLVOX

VOLVOX is a colonial, fresh-water organism, the body of which consists of a great number of independent flagellated cells. These cells are essentially similar to *Euglena* in structure, and like the latter have the holophytic type of nutrition. The presence of chlorophyll, just as in *Euglena*, makes the exact relationships of this organism a doubtful question. *Volvox* is classified with the unicellular, flagellated animals as a Protozoön or in the lowest order of Green Algae as a primitive plant form. Our main point of interest, however, in connection with *Volvox* lies in the fact that it is a primitive multicellular organism in which each individual consists of a great number of cellular units permanently associated to form a colony. In a *Volvox* colony each cell is a balanced structural and physiological unit capable of carrying on the necessary life processes independently of the other cells of the colony, except that certain cells may be specialized for reproduction.

In the higher multicellular plants and animals — all of which, in the final analysis, are essentially colonies of cells — there is an ever-increasing amount of cell specialization as we ascend in the scale of development. Along with this has come a division of labor between the cells, so that in these organisms the cells have become both structurally and functionally specialized to such an extent that they are capable of performing only certain of the life processes which are necessary for the welfare of the organism as a whole. Thus, for example, the functions of nutrition, irritability, movement, and numerous others are carried out in these higher types of organisms by groups of cells which are differentiated and adapted for their own particular work.

A. STRUCTURE OF VOLVOX

Volvox is large enough to be seen with the naked eye. It appears as a small, green, hollow sphere, the wall of which is composed of some ten or twelve thousand microscopic, flagellated, chlorophyll-bearing cells, together with a transparent, gelatinous, intercellular material, the **MATRIX**. The latter is formed as a

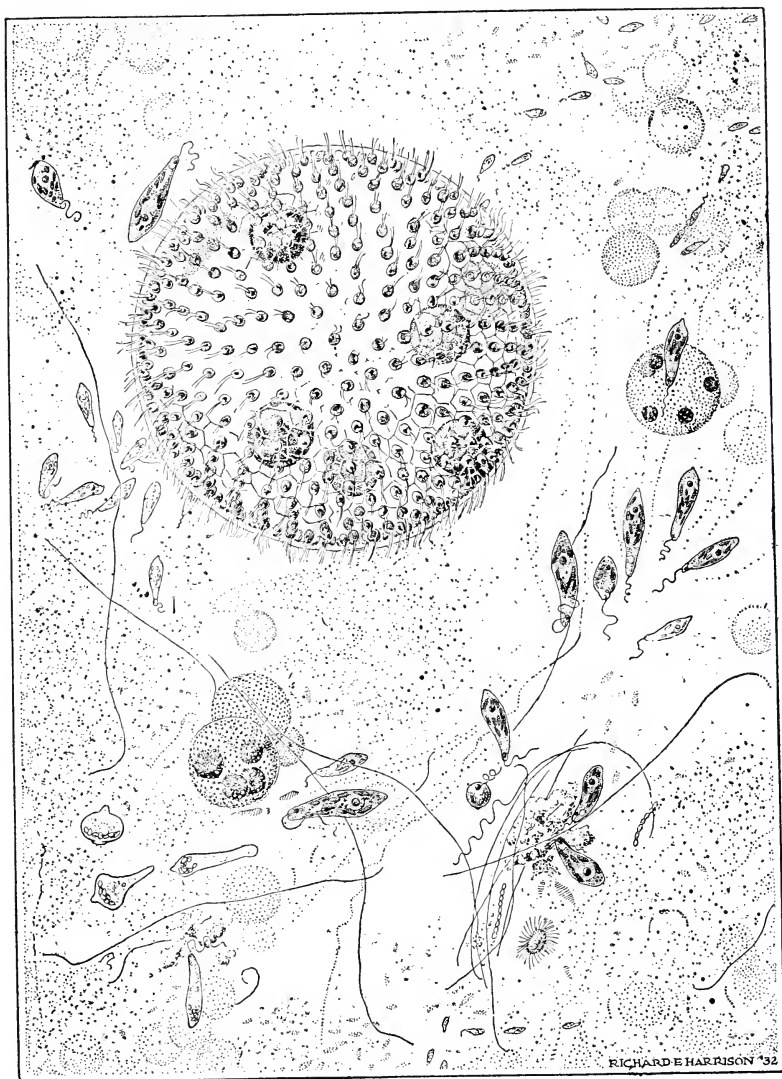


FIGURE 2

Three interesting types of flagellated organisms are here shown. There is, first, the colonial form, *Volvox*, which appears under the microscope as a greenish-colored sphere, slowly revolving by action of thousands of flagella. Usually, as shown, immature asexual colonies, also in action, are to be seen through the wall of the parent colony. The two unicellular Flagellates are *Euglena* and a closely related type, *Peranema* (lower left), which lacks chlorophyll. In most cases the flagella are shown. Actually, however, owing to their rapid vibration, they would not be seen in living cells.

common secretion and serves apparently to hold the cells of the colony together. (W. f. 30, A.)

The cells in a mature Volvox colony are of two kinds, the body, or SOMATIC CELLS, and the reproductive, or GERM CELLS. There are many more somatic than reproductive cells. Each somatic cell of Volvox is comparable in its general plan of organization with a single Euglena. However, it should be noted that each Volvox cell possesses two flagella, instead of one as in Euglena, and also that from each Volvox cell several cytoplasmic strands are given off which run through the matrix and connect with similar strands from the surrounding cells. Thus there is an anatomical and physiological continuity between the cells of the colony. (W. f. 30, B.)

Each of these bi-flagellated cells of Volvox is made up of ectoplasm and endoplasm, and contains a nucleus, contractile vacuole, stigma, and numerous chloroplastids. The cells are similar in structure to various other species of independent, flagellated Protozoa which never form colonies. The structure of the reproductive cells is noted below.

B. LIFE PROCESSES OF VOLVOX

1. *Metabolic Processes*

It has been emphasized that the somatic cells of Volvox are balanced structural and functional units, each capable of performing the basic life processes independently. These metabolic activities are performed essentially as in Euglena, which we have considered in the previous chapter. On the whole, Volvox is even more plant-like in its nutrition than Euglena, for it is exclusively holophytic.

The somatic cells of Volvox are responsible not alone for supplying food for their own individual needs, but also for certain needs of the colony as a whole; such as the formation and upkeep of the intercellular matrix and the nourishment of the reproductive cells of the colony, both of which are to be regarded as the property of the entire colony. On the other hand the function of reproduction in each colony is assigned to cells specialized for that purpose. Thus we have here a beginning of a division of labor between different types of cells, a condition which becomes more and more marked in the ascending scale of animal development.

2. *Reproduction*

The Volvox colonies reproduce either asexually or sexually. In both cases the process takes place by means of specialized cells which have become physiologically and structurally differentiated for the purpose of reproduction. Such cells lack flagella and, as will be seen, are otherwise structurally modified.

In asexual reproduction, certain large cells without flagella (PARTHENOOGONIDIA) begin to divide. The cells thus formed remain attached to each other and, as a result, very soon a new colony is formed. During the early stages of formation, the new group occupies a place in the wall of the original mother colony. But, as more and more cells are formed, it moves away from the wall into the central cavity of the mother colony, where, together with several other similar groups, it continues to grow by cell division. Finally, the wall of the parent colony is ruptured, thus permitting the new asexually-formed colonies to escape and to take up their independent existence. They have the same structure as the mother colony except that, for a time, they are not composed of so large a number of cells.

In the sexual reproduction of Volvox a considerable number of large germ cells, without flagella, are formed among the typical somatic cells. These germ cells gradually differentiate into either the male gametes, or SPERM, or the female gametes, or EGGS. The sperm of Volvox are formed by the repeated division of certain of the germ cells. Thus a plate-like body, composed approximately of 128 sperm cells, is formed from each germ cell of this type. When mature, these male elements separate and escape into the water. As is typically the condition in all organisms, the sperm of Volvox are free-swimming, and thus they are enabled to come into contact with the egg, which is inactive. (W. f. 30, A ♂, ♀.)

In the formation of the eggs, the potential female gametes increase in size but do not divide, and so each forms a large egg cell, with which later a sperm cell fuses permanently, thus bringing about a permanent union of the nuclear material of the two gametes. This is known as FERTILIZATION, and it constitutes the culmination and the fundamental feature of sexual reproduction in all organisms. In Volvox, the sexual reproduction generally occurs in the fall, and the ZYGOTES, which are formed from the fusion of the male and female gametes, secrete a protective covering

which enables them to withstand the lower temperatures of the winter season. In the following spring, when the water warms up, the zygote begins to divide and soon develops into a typical Volvox colony. It appears, therefore, that the sexual method of reproduction, with the consequent zygote formation, enables the organism to survive unfavorable environmental conditions.

TEXTBOOK REFERENCES

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V. PARAMECIUM

PARAMECIUM is a widely distributed representative of a very highly specialized class of Protozoa, known as the Infusoria. Various species of Paramecium are commonly found in fresh-water puddles and ponds, in almost all regions of the world. The great majority of Infusoria are free-swimming forms possessing cilia which, as previously noted, furnish a very efficient method of locomotion. Paramecium shows a much greater specialization of the different parts of the cell than does either Amoeba or Euglena. Thus, we find that within the limits of the single microscopic cell, which constitutes the body of this animal, special structures are provided for carrying on various essential activities, such as nutrition, excretion, reproduction, locomotion, and defense. Paramecium, therefore, provides an excellent example of the high degree of structural differentiation which may be attained in a unicellular animal.

A. STRUCTURE OF PARAMECIUM

When a drop of water containing Paramecia is examined with the naked eye, it will be found with careful observation that the animals can just barely be seen as tiny, rapidly moving bodies. A microscopic study shows that Paramecium, when viewed as a flat surface, has somewhat the shape of a shoe sole, and on this account it is often referred to as the 'slipper animalcule.' When a transverse section through the animal is studied, it is found to be nearly circular in outline. In swimming it will be noted, contrary to what might be expected, that the animal normally moves with the more blunt end pointed forward. This end is regarded as the anterior end of the body, and the opposite, more pointed extremity as the posterior end. (B. f. 3.)

Beginning at the blunt anterior end, and continuing posteriorly to a point slightly back of the middle of the body, is a depression, known as the PERISTOME, which gives the animal an asymmetrical appearance. It becomes deeper as it passes posteriorly, and finally ends in a definite tube, the GULLET, which lies quite deep in

the cytoplasm. The surface of the animal, including the peristome, is uniformly covered with fine, hair-like filaments, the CILIA, which continually beat in the water in a coördinated manner and thus enable the animal to swim in a rapid, vigorous fashion. Some of them also aid in securing food by driving a current of water along the peristome toward the gullet. (W. f. 27.)

Enclosing the ectoplasm of Paramecium is a thin, secreted cell wall, or pellicle, which shows very fine regular markings, or striations, on the surface. Innumerable fine strands of ectoplasm project through the pellicle. These constitute the cilia which form a uniform covering over the surface of the animal. The pellicle of Paramecium is much more rigid than that of Euglena, so that normally the animal maintains a definite shape. However, when an individual is pressed against pieces of débris or is under the influence of various other environmental conditions, a considerable variation in shape takes place.

Embedded in the ectoplasm is a single layer of highly differentiated, flask-shaped bodies, known as the TRICHOCYSTS. They lie with their long axes perpendicular to the surface of the ectoplasm. The base of the structure is toward the interior of the animal, and the other end opens through the ectoplasm to the exterior. These trichocysts are filled with a fluid which hardens and becomes thread-like when it is expelled into the water. The discharge of the trichocysts can be brought about experimentally by adding a little dilute acid to the culture medium and thus irritating the Paramecia. In some species of Protozoa it has been found that the trichocysts have a paralyzing effect upon other living organisms, and they are therefore regarded as weapons useful either in the capture of other animals for food or in the repelling of attacks by enemies. In Paramecium, however, the function of these bodies seems to be essentially defensive.

The endoplasm of Paramecium is, as has been found to be the case in other forms, somewhat less viscous than the ectoplasm. It also contains many granules of various sizes, some of which are constituent parts of the cytoplasm, while others are merely temporary metaplasmic particles. The endoplasm also contains numerous GASTRIC VACUOLES and a characteristic nuclear apparatus composed of a large MACRONUCLEUS and one or two small MICRONUCLEI,¹ the latter lying on or near the macronucleus.

¹ W. p. 54, *footnote*.



FIGURE 3

This drawing, which was made from life, depicts *Paramecium* and *Vorticella* as seen under normal living conditions, at a magnification of about 300 diameters. In the foreground, two *Paramecia* are seen swimming near a portion of the stem and leaf of the green, water-living plant, *Elodea* (p. 12). In the upper right a carnivorous Ciliate, *Didinium*, is seen attacking a *Paramecium*, and to left a pair of conjugating *Paramecia* is shown. Attached to the *Elodea* leaf are numerous specimens of the 'bell-animalcule' *Vorticella*, in various stages of contraction as described in the following chapter.

Lying between the ectoplasm and endoplasm are two CONTRACTILE VACUOLES, one near each end of the animal. Each contractile vacuole consists of a large central spherical vacuole and a number of radiating canals which open into it; the whole forming a star-shaped structure.

B. LIFE PROCESSES OF PARAMECIUM

1. *Nutrition*

Paramecium exhibits a typical holozoic type of nutrition. The food consists for the most part of various kinds of Bacteria together with a number of species of tiny Flagellates, all of which are obtained from the surrounding fluid medium. The cilia lining the peristome play an important rôle in capturing the food. The coördinated beat of these cilia is so directed as to cause a continuous current of water, containing the food materials, to sweep down to the posterior end of the peristome. Here the particles pass through the mouth opening into the tubular gullet. The particles of food collect at the posterior end of the gullet and form a gastric vacuole in the endoplasm which, when it has attained a certain size as a result of the continued increase in the number of captured food particles, is detached from the end of the gullet. This apparently takes place as the result of a contraction of the surrounding endoplasm. As soon as one gastric vacuole is detached from the end of the gullet another one at once begins to form in the same place.

The fully formed and detached gastric vacuole, as a result of the continual streaming movement, or CYCLOSIS, of the endoplasm, is moved in a definite path through the body. It is first carried backward with the endoplasmic current and almost reaches the posterior end of the animal. It is then carried forward along the dorsal surface to the anterior end of the body, where the protoplasmic motion is again reversed, and the gastric vacuole passes first ventrally and then posteriorly toward a definite ANAL SPOT which is situated on the ventral surface of the body, near the posterior end. Emphasis should be laid upon the fact that this process of cyclosis, which results in a definite orderly movement of the gastric vacuoles through the endoplasm of Paramecium, is due to a streaming of the endoplasm, the food vacuoles playing an entirely passive rôle.

During this movement of the gastric vacuoles, the process of digestion of the food material takes place. The results of experimental studies show that the chemical actions, which take place in the digestion of food in the gastric vacuoles of *Paramecium* and in many other Protozoa, are fundamentally the same as take place in the digestion of food in higher forms of animal life. In all cases the food is acted on by the secreted enzymes which render it soluble and capable of being assimilated by the protoplasm.

Paramecium does not show a definite selection of food as was noted in *Amoeba*. Almost any minute particle, whether it be food or not, which comes in the range of the current of water caused by the beat of the cilia in the peristome, may be carried along and deposited in a food vacuole. This can be well-illustrated by adding a small amount of an indigestible substance, such as powdered carmine or other finely ground material, to the fluid which contains *Paramecia*. A microscopic study of such a preparation shows that the indigestible carmine particles are collected to form gastric vacuoles in just the same way as are food particles. The carmine-filled gastric vacuoles are also detached from the end of the gullet and carried in the normal way through the endoplasm, finally ending at the anal spot, through which the indigestible carmine particles are egested.

2. *Respiration and Excretion*

The basic features of respiration (income of oxygen and outgo of carbon dioxide) and excretion (the elimination of metabolic wastes from the cell) are common to every living cell of every type of organism. Also in the unicellular animals, the mechanisms necessary for performing these functions are much the same. Thus the same methods are used in *Paramecium* as in *Amoeba*, which are the excretion of liquid wastes through the contractile vacuole apparatus and the interchange of gases at the surface of the body, and probably also to some extent by means of the contractile vacuoles.

The two contractile vacuoles in *Paramecium* maintain practically constant positions, one near the anterior end and the other near the posterior end of the body. The liquid wastes first collect in the radiating canals which surround each contractile vacuole and then pass from the former into the central cavity, from which they are expelled to the exterior later by the contraction of the

surrounding endoplasm. The two vacuoles, as a rule, contract alternately.

3. *Reproduction*

In *Paramecium*, just as in the other unicellular forms previously noted, reproduction occurs by binary fission, that is, by the mitotic division of the cell into two daughter cells. *Paramecium* and most other ciliated forms divide transversely, whereas in *Euglena* and other Flagellates it will be remembered that the division is longitudinal. (W. f. 28.)

During the process of cell division, which has been very completely studied in *Paramecium*, there is, first, a division of the micronucleus into two equal parts. Then the macronucleus, having elongated somewhat, also divides into halves. Following this, the cytoplasm in the center of the animal begins to constrict transversely. The constriction continues to deepen, and in the course of an hour or so, the animal is completely divided into two daughter cells, each of which, although at first only one-half the normal size, nevertheless contains the normal nuclear structure and most of the other characteristic features. Structural modifications are occurring synchronously with the division of the nuclei and the cell body, so that when the two halves separate, the animal formed from the anterior half has a newly formed posterior end, and the animal resulting from the posterior half has a newly formed anterior end with the various specialized structures, such as the peristome and contractile vacuole. This process of cell division normally may take place two or three times within twenty-four hours.

The life history of *Paramecium*, however, is not so simple as might be thought from the above description of reproduction by binary fission, for it has been shown that after reproduction has gone on for a considerable number of generations in this manner, a reorganization of the cytoplasmic and nuclear material typically occurs. It is probable that this protoplasmic reorganization can take place either by *ENDOMIXIS* or by *CONJUGATION*.

ENDOMIXIS. If *Paramecia* are kept under certain culture conditions in which they can be observed day by day, it will be found that a lowering of the division, or reproduction, rate occurs at quite regular intervals. This reduction is apparently independent of the food or of other environmental conditions. In other words,

although there is plenty of food, the animals are not able to reproduce as rapidly as usual, due, supposedly, to some internal factor or factors. A depression of this type is the external evidence of the beginning of a periodic process of intracellular reorganization and adjustment between the cytoplasm and nuclear material in each animal, known as **ENDOMIXIS**.

The details of the process of endomixis in the species known as *Paramecium aurelia*, which normally has two micronuclei, may be outlined as follows:

(1) Each of the micronuclei divides twice to form a total of eight micronuclei. (W. f. 171, *A, B, C*.)

(2) The macronucleus fragments and finally is completely broken down and dissolved in the cytoplasm. (W. f. 171, *B*.)

(3) Six out of eight of the newly formed micronuclei degenerate. (W. f. 171, *D*.)

(4) The cell divides, and one micronucleus goes to each daughter cell. (W. f. 171, *D, E*.)

(5) The micronucleus in each cell divides twice to form four nuclei, two of which become macronuclei and two become micronuclei. (W. f. 171, *F, G*.)

(6) Each of the two cells now divides, thus giving four normal cells. (W. f. 171, *I, J*.)

From the above description, it can be seen that the process of endomixis brings about a complete, periodic reorganization of the entire nuclear apparatus of an animal and a new adjustment between cytoplasm and nucleus. When the process has been completed, the normal rate of division, which has been temporarily depressed, is again established, and the animal — if the environmental conditions are suitable — can grow and reproduce by binary fission with the normal rapidity for some weeks until the onset of the next endomictic period.

CONJUGATION. Considering next the process of conjugation, which is of very general occurrence among the Protozoa, it should be emphasized that, while it is a process of nuclear and cytoplasmic reorganization, it also involves, first, an interchange of nuclear material between two animals and, second, the permanent fusion (**FERTILIZATION**) in each animal of the nuclear material received with a portion of the nuclear material already there to form a composite nucleus, or **SYNKARYON**.

The first step in the process of conjugation in *Paramecium* is

the meeting and temporary fusion of two animals. This occurs in such a way as to involve a considerable portion of the oral surfaces. Thus a temporary protoplasmic bridge is formed between the animals. Coincident with this external fusion, as shown in figure 3, a series of nuclear reorganization phenomena begins in each animal which are of the same general character as in endomixis, and which in *Paramecium aurelia* may be outlined as follows:

(1) The two micronuclei in each animal become somewhat enlarged, and two mitotic divisions occur, resulting in the formation of eight micronuclei in each animal. The macronucleus degenerates and entirely disappears. (W. f. 170, A, B, C.)

(2) Seven of the eight newly formed micronuclei in each animal degenerate and the remaining one divides again to form two bodies, termed GAMETIC NUCLEI. (W. f. 170, D, E, F.)

(3) One of the nuclei (STATIONARY GAMETIC NUCLEUS) remains in the animal where it was formed, but the other (MIGRATORY GAMETIC NUCLEUS) moves across the protoplasmic bridge into the other animal, where it permanently fuses (FERTILIZATION) with the stationary gametic nucleus there present to form the synkaryon. (W. f. 170, F, G, H.)

(4) The exchange of nuclear material having been effected, the two animals separate. In each exconjugant the new nuclear apparatus is then built up by the division and differentiation of the synkaryon. It divides twice in each exconjugant to form four micronuclei, two of which remain as micronuclei and two enlarge to form macronuclei. The two micronuclei in each exconjugant then divide. This is followed by the division of each exconjugant into two normal cells, each with a macronucleus and two micronuclei. A period of reproduction by the regular process of cell division now follows. (W. f. 170, I, J, K, L.)

4. Adaptation

The fact that *Paramecium*, because of its highly coördinated, ciliary locomotor apparatus, is able to move in any direction with considerable rapidity, makes it a valuable animal for studying its reaction or 'motor response' to various kinds of external stimuli. The latter may be caused by various changes in the environment as a result of the action of chemical, electrical, photic, or thermal phenomena. If, for example, a drop of some unfavorable fluid is added to the culture medium containing *Paramecia*, when

the animals come into contact with it, they will give a characteristic 'avoiding reaction.' In such a case an animal first backs off a little way from the unsuitable region, changes the course of direction somewhat, and then moves forward in an endeavor to avoid the source of irritation. If the direction taken accomplishes this, then the animal will continue its course ahead until some other external factor intervenes to bring about a change of direction. If the direction taken again brings the animal into contact with the unfavorable medium, the avoiding reaction is again given, and another course is tried. (W. f. 225.)

In locomotion, the cilia covering the body of the animal exhibit a beautifully coördinated, beating movement. Their action usually drives the animal forward, but by a reversal of the ciliary action, the animal is able to move backward with equal rapidity. It is obvious, of course, that the movements of all the cilia must be in unison if a definite progression of the animal is to be obtained. It is an interesting problem to determine how the beats of almost innumerable cilia can be controlled in such a way as to bring uniformity of action, or how the action of all the cilia can be reversed suddenly, and the animal thereby driven in the opposite direction. It would seem as if there must of necessity be some sort of complicated controlling mechanism to bring about such coördination, and, as a matter of fact, evidence has recently been found in several species of Ciliates, including *Paramecium*, which indicates that a coördinating 'neuromotor' apparatus of differentiated cytoplasm is present. Presumably this apparatus functions somewhat like the nervous system in the higher forms of animals. (W. f. 135.)

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VI. VORTICELLA

VORTICELLA is another interesting example of a ciliated, unicellular animal belonging to the Infusoria. It exhibits a number of important structural features some of which are quite different from those in Paramecium. Thus the cilia, instead of forming a uniform covering, are, in general, restricted to a definite anterior region where they function in the capture of food particles. Vorticella has a distinctive bell-shaped body and is often referred to as the 'bell-animalcule.' It is usually found attached to some solid material in the water. This attachment is by a long contractile stalk. Our interest in Vorticella lies chiefly in the unusually high development of its various structural features as is shown, for example, by the presence of definite contractile fibers in the stalk which are suggestive of the specialized contractile elements, the muscle tissue, of the higher animals. Another point of interest is the development, in closely related species, of colonial types with several functionally independent individuals attached to a common stalk — a condition essentially similar to that already noted in Volvox.

A. STRUCTURE OF VORTICELLA

Projecting from the large, flaring bottom (PERISTOME) of the bell-shaped body is a circular structure, the DISC. The edge of the disc (EPISTOME) is in close contact with the peristome around most of its circumference. At one point, however, the epistome and peristome are separated, and a considerable space is left between them, which is known as the VESTIBULE. In this vestibule, the food particles are first collected and then passed from it through a mouth opening into the gullet. The comparatively long, contractile stalk, which continues from the apex of the body, is an extraordinary bit of protoplasm, as will be seen from the description given below. (W. f. 18, C.)

The body of Vorticella is made up of an outer layer of ectoplasm and an inner portion of endoplasm. There is a comparatively heavy secreted pellicle which encloses the entire body and stalk

of the animal. The ectoplasm also continues throughout the length of the stalk. It should be noted that it is in the ectoplasm that the specialized contractile fibers, or MYONEMES, are formed. The endoplasm of Vorticella, as in other protozoan forms, makes up the greater portion of the animal's body, but it does not continue into the stalk. In the endoplasm are numerous gastric vacuoles, a large U-shaped macronucleus, and a small micronucleus. There is usually a single, large contractile vacuole.

STALK AND AXIAL FILAMENT. In the center of the stalk and running its entire length is a noteworthy structure, the AXIAL FILAMENT. This is the definite contractile element and consists of a great number of fine, individual fibers, the myonemes, that arise in the ectoplasm of the bell and converge to form the axial filament in the stalk. The myonemes are of interest because they represent the lowest type of differentiated contractile fibers which may be compared in their function to the contractile muscular elements of higher animals. (B. f. 3.)

When the axial filament of the stalk is contracted, it looks like a tightly wound spiral spring, and all degrees of contraction can be observed between this condition and a nearly straight rod. When a contraction of the axial filament occurs, the myonemes in the wall of the bell usually also contract, and this brings about a contraction of the flaring peristome and the disc of the cell body. As a result, the bell-shape is temporarily modified, and the body of the animal becomes almost spherical. A number of such individuals are shown on the under surface of the leaf in figure 3.

CILIA. The cilia do not form a uniform coating over the outer surface as in *Paramecium*, but are restricted in the attached, or sessile, animals to the edges of the peristome and epistome, and to the vestibular space where they are differentiated to form a vibrating, or UNDULATING MEMBRANE. The chief function of the cilia in Vorticella is to create a water current which will sweep food particles into the vestibule and thence through the mouth into the gullet. The waste products of the animal are also removed from the vestibule by ciliary currents.

The discussion of Vorticella, so far, has been confined to the sessile animals with stalks. But as a result either of unfavorable environmental conditions or of cell division, free-swimming animals, without stalks, may be found occasionally. In such cases an additional band of cilia specialized for locomotion is developed.

This band encircles the body near where the stalk is normally attached, and the stalkless animal is able to swim freely through the water. This is a temporary condition, however, and when a suitable environment is found a new stalk is developed, and the locomotor cilia are lost.

B. LIFE PROCESSES OF VORTICELLA

1. *Nutrition*

The nutrition of *Vorticella* is holozoic and essentially the same as that of *Paramecium*. The food particles, consisting largely of Bacteria which are swept into the vestibule and through the mouth, are collected at the base of the gullet in a gastric vacuole. As in *Paramecium*, there is a definite cyclosis of the endoplasm, as the result of which the gastric vacuoles are carried along in a regular path through the endoplasm. The indigestible refuse is egested through a definite anal spot which opens into the vestibule. Carmine particles can be used with *Vorticella* just as with *Paramecium* to show various features of the process.

2. *Respiration and Excretion*

The intake of oxygen and the excretion of liquid and gaseous wastes, resulting from the katabolic processes in the organism, are also similar to *Paramecium*. There is a single large contractile vacuole which expels the body wastes to the exterior through an opening into the vestibule. Respiration also occurs over the entire surface of the cell body.

3. *Reproduction*

In *Vorticella*, asexual reproduction by binary fission takes place very frequently if conditions are favorable. Three or four divisions a day are not uncommon, so that, from a single animal, sixteen or even more typical individuals may be formed within twenty-four hours. In dividing, the micronucleus is the first to act, then the macronucleus, and, finally, the cell body. The splitting of the cell body begins in the region of the peristome and proceeds toward the apex of the bell where the stalk is attached. For a short time after the body has completely divided, two small but complete individuals may be attached to a single stalk. Shortly afterwards, however, one animal develops a temporary band of

locomotor cilia, as mentioned above, and breaks away from the stalk as a free-swimming individual. It soon settles down, develops a new stalk, and, when it has grown to normal size, may reproduce again.

CONJUGATION. The process of conjugation in *Vorticella* is somewhat different from that noted in *Paramecium*, in which two individuals of the same size (ISOGAMOUS) fuse temporarily for the purpose of interchanging nuclear material, and then separate. In *Vorticella* there is a permanent fusion of a small, specialized free-swimming individual, the 'MICROGAMETE,' with a normal-sized, attached individual, the 'MACROGAMETE.' This process is known as ANISOGAMOUS conjugation. We may regard the two types as constituting the male and female elements respectively. The main features of conjugation in *Vorticella* are as follows:

(1) The 'female macrogamete' is, to all appearances, a typical *Vorticella*.

(2) The 'male microgamete' is a small atypical cell without a stalk. It is formed by the rapid division of an apparently typical *Vorticella* into four small cells, all of which quickly separate and swim away to seek a macrogamete.

(3) When a microgamete comes into contact with a macrogamete, it fuses with it permanently. The place of attachment is generally at the apex near where the stalk is attached. Fertilization with synkaryon formation occurs through the fusion of the nuclear material of the microgamete and of the macrogamete. Thus the essential features of the nuclear changes in the conjugation of *Vorticella* agree with those of *Paramecium*.

4. *Adaptation*

It has been noted above that free-swimming, stalkless *Vorticellae*, which bear an additional band of cilia for locomotion, are occasionally found. These individuals are regularly formed at the time of reproduction, but it is known that they may also occur when the environmental conditions become unsuitable. Apparently the development of such free-swimming individuals is to be regarded as an adaptive measure by means of which the possibility of finding better living conditions is supplied.

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Consult the list given for the previous chapter (p. 47).

VII. GRANTIA

IN our previous consideration of *Volvox* it was noted that each of the somatic cells of the organism "is a balanced structural and physiological unit capable of carrying on the essential life processes independently of the other cells of the colony." A structural and physiological differentiation of the cellular units, save for reproduction, was not apparent. A somewhat different and more advanced condition with regard to the cellular units is to be found in *Grantia*, which may now be indicated.

Grantia is a marine animal of low development which belongs to the phylum Porifera, or Sponges, as they are more commonly called. This group is generally regarded as constituting the most primitive group of the true Metazoa, that is, multicellular animals in which the numerous constituent cells of the mature organism are not all alike, as in *Volvox*, but, on the other hand, are structurally and functionally differentiated, so as to perform certain definite activities for the benefit of the organism as a whole. The differentiation of the cells in Sponges is very meager as compared with that present among the cells of the higher Metazoa, such, for example, as a Frog, but it is sufficient to mark the separation from the multicellular protozoan types, noted in *Volvox*.

The Sponges as a group are characterized by the presence of peculiar secreted spicules in the body wall, which constitute the essential skeletogenous, or supporting, elements. In *Grantia* these skeletal elements are calcareous in their nature, but in other species of Sponges they may be composed of silica or of a characteristic organic material, known as SPONGIN, which gives the bath sponge of commerce its valuable qualities.

A. STRUCTURE OF GRANTIA

Grantia is a small, vase-shaped animal measuring about five-eighths of an inch in length and one-fourth of an inch in diameter through the largest part of the body, which is near the center. The base, or closed end of the 'vase,' is normally attached to a solid, submerged object, such as a piece of wood or stone, lying some distance

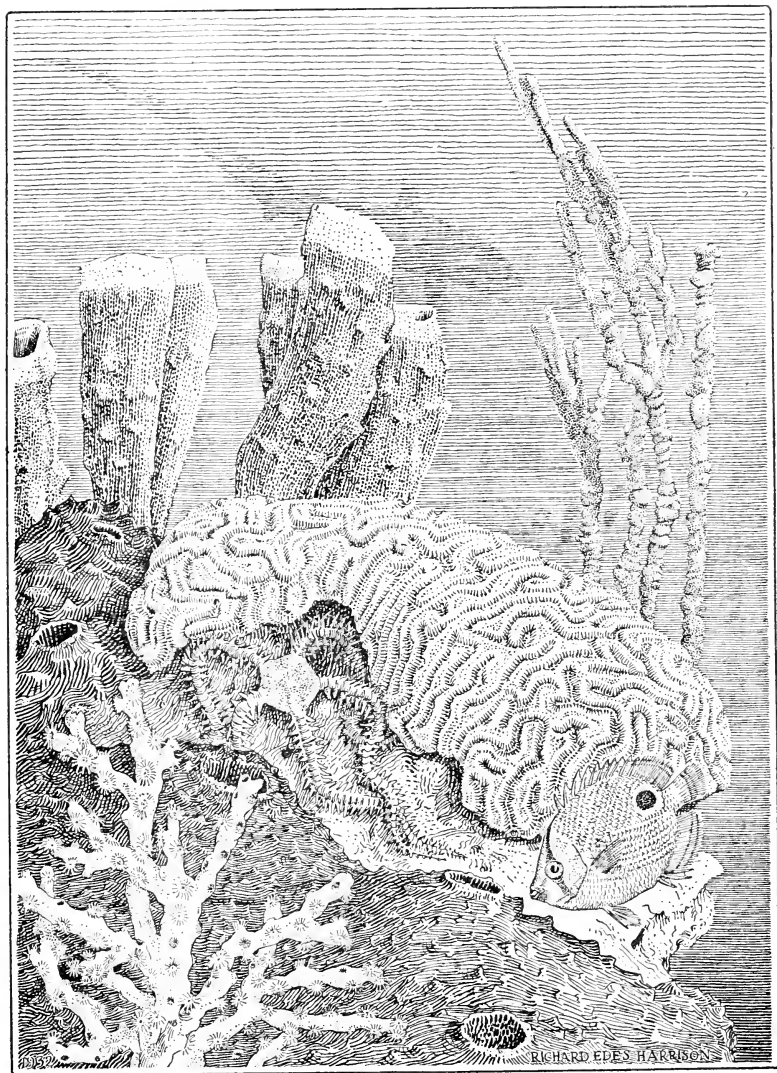


FIGURE 4

This Bahama Reef habitat group was adapted, by kind permission, from an exhibit in the American Museum of Natural History in New York. It gives striking evidence of the abundance and variety of marine life. Forming the base of the group is a living Bath Sponge (*Euspongia*), and to the back and left several vase-shaped Sponges of the genus *Spinosella* are seen. Three Corals are shown; the Brain Coral (*Meandra*) with an Echinoderm, the Brittle Star (*Ophiura*), crawling along the side; to the right and back, *Millepora* extends toward the top of the figure; and the calcareous Bush Coral (*Oculina*) in the left foreground. The beautifully marked tropical fish is *Chaetodon*.

under the surface of the water. The top of the vase has a tiny circular opening, or **OSCULUM**, through which there is a continuous flow of water outward from the central **GASTRAL CAVITY**. The latter extends practically the entire length of the animal's body. The general body plan can, perhaps, best be seen in a longitudinal section passing through the entire length of the animal from base to osculum and thus dividing it into halves. Such a section will reveal a comparatively thick body wall enclosing the gastral cavity. (W. f. 35, C.)

The outer surface of the body wall appears fairly smooth and continuous when examined with the naked eye. However, when microscopically examined under the proper conditions it will be found to be perforated with thousands of tiny openings, or **OSTIA**, which lead into the horizontal **INCURRENT CANALS**. The walls of the incurrent canals contain pores (**PROSOPYLES**) which connect with flagellated **RADIAL CANALS**. The latter lie parallel to the incurrent canals and open into the central gastral cavity but do not extend entirely to the outer body surface. During life there is a continuous flow of water through the incurrent canals, prosopyles, and radial canals, then into the gastral cavity, and, finally, to the exterior through the osculum. This flow of water in *Grantia* is brought about by the action of the flagellated **COLLAR CELLS**, or **CHOANOCYTES**, lining the radial canals and is essential to its life processes, as will be noted in the later discussion. (W. fs. 35, B; 36, B.)

A study of the early development of *Grantia* discloses the fact that the body wall consists primarily of three layers, the cellular elements of which reveal considerable structural and functional differentiation. There is, first, an outer **DERMAL REGION** which covers the surface of the body. It contains the incurrent canals, and we may regard these as arising through a series of parallel infoldings of the outer dermal layer. Second, there is an inner **GASTRAL REGION** which forms the lining of the gastral cavity. It contains the radial canals, and we may regard these as arising through a series of parallel outfoldings of the inner gastral layer. Finally, there is the so-called **MIDDLE REGION** which is composed of a jelly-like matrix containing amoeboid cells in abundance. It lies between the dermal and gastral layers and thus separates the incurrent and radial canals, and is perforated by the prosopyles which, as noted above, connect these two systems of canals.

Altogether there are some thirteen different types of cells present in the three layers of this sponge, all of which perform essential functions in the economy of the organism. Summarizing the duties of the various types of cells, it may be said that those of the dermal region are largely concerned with the protection and the support of the body tissues through the formation of the covering and skeletal elements. The middle region contains the amoeboid cells which are concerned with the transportation of nutritive materials and reproduction, while the gastral region contains cells of only one type, the collared, flagellated choanocytes, which are chiefly nutritive in function.

B. LIFE PROCESSES

From the preceding description of the chief structural features of *Grantia*, it is evident that, in general, the cells are structurally modified and variously adapted for the particular needs of the animal. In agreement with the structural modifications, the cells are also functionally specialized in certain instances, as, for example, in the case of those forming the supporting elements, to such an extent that they are incapable of performing all the life processes necessary for the maintenance of the organism as a whole as are the balanced, independent cells of a multicellular protozoön like *Volvox*. In *Grantia*, as elsewhere, cell specialization is inevitably associated with a DIVISION OF LABOR between the differentiated cellular groups, each of which is concerned with a certain function or functions necessary for the existence of the complete organism. Such a condition makes it necessary that each cell group share in the benefits derived from the activities of all the other specialized cell groups.

1. *Nutrition*

Grantia as a holozoic organism is dependent for its food supply upon organic substances in a solid form. These it finds in a very finely divided condition in the water current which, as has been noted, is continually flowing through the gastral cavity of the organism. It will be recalled that this flow of water is due to the coördinated actions of the flagella of the choanocytes which line the radial canals of this organism.

But these choanocytes have not merely a mechanical function in nutrition, they are also the agents for the ingestion and digestion

of the food particles. These functions they perform in essentially the same manner as do protozoan cells; that is, the food is actually engulfed, or ingested, and the process of digestion takes place within the body of each individual cell. This constitutes INTRACELLULAR DIGESTION and is to be differentiated from INTERCELLULAR DIGESTION present in the higher types of Metazoa in which certain of the cells lining the digestive tract secrete the digestive fluids, or enzymes, into a common cavity where the food is digested, and from which it is later absorbed for distribution among all the cells of the organism (pp. 85-87).

Thus we have the choanocytes of *Grantia* securing the nutritive materials for the entire organism. It may be asked at this point as to how the other cells of the organism secure the necessary supply of the food captured and digested by the choanocytes. It is known that the excess of nutrient materials is given up by the choanocytes for general distribution. It appears to be a function of the amoeboid wandering cells of the middle layer to receive and transport these substances to the various other types of cells.

2. *Respiration and Excretion*

There are no specialized cells in *Grantia* for the performance of the respiratory and excretory functions of the entire organism. Accordingly each cell is responsible for the performance of these necessary cellular functions. However, the more favorable position of the cells of dermal and gastral regions, with respect to the surrounding oxygen-containing water, as compared with the enclosed cells of the middle region, indicates that the latter cells pick up their oxygen from, and pass off their wastes through, the dermal and gastral cells. Here again it is apparent that the cells of *Grantia* are close to the protozoan level with respect to these two functions.

3. *Reproduction*

Grantia may reproduce asexually by budding, or sexually by the production of highly organized germ cells which have their origin in the middle region of the body. In asexual reproduction, rapidly dividing cells, apparently originating from all three layers of the body, gradually form a small outgrowth, or bud, near the base of the parent animal. The bud gradually enlarges and differentiates to form the fully developed individual. Frequently it

remains attached to the parent body, other buds develop, and thus a colony of attached individuals arises.

In sexual reproduction, differentiated sex cells, both male and female, arise in the middle layer of the same individual. It will be remembered that an HERMAPHRODITIC condition of the same nature as this was noted previously in *Volvox*, and other examples will be found in the higher types noted later. The mature sex cells, both eggs and sperm, are discharged into the water, and the fertilization which ensues produces a zygote which divides and gradually develops independently into the mature *Grantia*. In certain fundamental features of embryonic development, *Grantia* and the Sponges in general are unique. On this account it will be well to defer a description of the metazoan development until *Hydra* is considered in the next chapter.

4. *Adaptation*

It has previously been emphasized that protoplasm, wherever found, is responsive to environmental stimuli—it is irritable material—and this characteristic is responsible for the power of adaptation which living organisms possess. Now although all protoplasm is irritable it becomes necessary in the higher types of animals to develop a special type of cell, the nerve cell, or NEURON, and to combine these into a complex NERVOUS SYSTEM which functions for the reception of stimuli and for the inauguration of the proper coördinated response. In the Sponges, this stage of nerve cell development has not been attained, and so the stimuli must be received directly by the various cells.

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VIII. HYDRA

HYDRA is a widely-distributed, fresh-water animal that is particularly well-adapted for consideration at this time since it exhibits a number of features which are important as a groundwork for our later study of the much more complex animal types. Thus the sac-like body plan of Hydra, with the enclosed common digestive cavity into which the mouth opens, is in line with the condition found in the higher animal types and quite unlike the aberrant condition previously noted in the Sponge in which a digestive cavity of this type is entirely lacking. Hydra exhibits a marked radial symmetry which may be regarded as the primitive, or basic, type from which the two-sided, or bilateral, symmetry of the higher types has arisen. On the whole, the differentiation of groups of cells for various phases of structure and function is probably more advanced in Hydra than in the Sponge. This is particularly true with regard to the nerve cells, or neurons, which really form a primitive nervous system in Hydra.

A. STRUCTURE OF HYDRA

In its general structure, Hydra may be compared to a tubular sac, the closed, attached end of which is known as the FOOT, or BASAL DISC. At the opposite end of the tubular sac, known as the HYPOSTOME, there is the mouth opening surrounded by several long, flexible TENTACLES. The exact number of tentacles varies in the different species of Hydra. The mouth opens directly into a single large central cavity, known as the ENTERIC CAVITY. The tentacles are hollow structures also, and in each there is a central cavity which is a continuation of the enteric cavity. The body of Hydra is composed of a very large number of cells. These cells are clearly divided into an outer layer, the ECTODERM, which covers the entire animal, and an inner layer, the ENDODERM, which lines the entire enteric cavity even to the tips of the tentacles. Between the ectoderm and endoderm there is a thin layer of transparent, non-cellular material known as the MESOGLOEA. (W. f. 57.)



FIGURE 5

This drawing, which was made from a culture in the Osborn Zoölogical Laboratory, Yale University, shows many Brown Hydra (*Pelmatohydra*) living under normal conditions. They are attached to water plants or other convenient objects at almost every angle. Continual movement is noted. The animals, searching for prey, extend their tentacles to great lengths and then contract them, and the entire body also is contracted or expanded as the conditions happen to require.

ECTODERM. As will be noted in the succeeding paragraphs, there are several kinds of ectoderm cells. However, by far the greatest number of the ectoderm cells are known as the **EPITHELIO-MUSCULAR** cells which form the covering, or **EPITHELIUM**, of the body. As indicated by their name, these epithelial cells also contain contractile elements located near their inner ends, which function in a similar way to the muscle cells in the higher types of animals. In the basal disc, some of the epithelio-muscular cells also secrete a sticky fluid which enables the *Hydra* to attach itself to various objects.

One end of the epithelio-muscular cells is typically somewhat larger than the other, and these large ends, closely fitted together, form the outer surface of the body. The inner portions of these cells are generally not in close contact with each other, and the spaces between often contain another type of ectodermal cell known as the **INTERSTITIAL CELLS**. Some of these interstitial cells may become further differentiated into either **CNIDOBLASTS** or into specialized **GERM CELLS**. The latter will be considered in the section on reproduction.

The cnidoblasts, developed from the interstitial cells, become highly specialized to form the defensive and offensive weapons of *Hydra*, known as **NEMATOCYSTS**, or stinging capsules. Except in the region of the basal disc, they are scattered in considerable numbers over the entire surface of the body. They are present in the greatest numbers on the tentacles, where they are consolidated to form 'batteries of nematocysts' which may be easily seen as bands encircling the tentacles. Occupying the center of this type of cell is a remarkable structure, the nematocyst proper, which consists essentially of a long, coiled, filamentous tube attached to a spine-covered base. The tube contains a poisonous substance. A rather rigid spine, the **CNIDOCIL**, projects from the outer surface of these cells into the water surrounding the animal. It is apparently sensitive to contact.

Under the proper conditions, the nematocyst can be exploded. When this occurs, the coiled, poisoned tube bursts through the surface of the cnidoblast, uncoils with great rapidity and with sufficient power to penetrate the tissues of various small animals with which *Hydra* comes into contact. In such a case the attacked animal, paralyzed by the action of the poison, is captured by the tentacles of *Hydra* and conveyed to the mouth. In addition to the

type of nematocysts just described, which paralyze the prey with a poisonous substance, there is another smaller type which shows the same general structure, but lacks the poison. The coiled, filamentous tubes of this type of nematocyst curl around any small projecting part of an animal which the Hydra is attempting to capture, and in this way hold it firmly so that it can be conveyed to the mouth.

In addition to the epithelio-muscular cells and interstitial cells, there are also developed from the ectoderm a considerable number of NERVE CELLS which are scattered among the epithelio-muscular cells, and are also found lying deeper in the endoderm layer. The bodies of these neurons of Hydra have become somewhat modified in their structure from that of a typical cell in that each possesses processes which connect with other nerve cells and thus form a widely distributed NERVE NET. The latter constitutes a primitive type of NERVOUS SYSTEM equipped to receive stimuli and to bring about the proper coördinated response of the various parts of the body as in the higher animal forms.

ENDODERM. The endoderm cells, which line the enteric cavity and are responsible for the nutrition of the animal, show considerable variation from the ectoderm cells. Some of them are actually able to take solid food particles within the cell body in typical protozoan fashion, and digest them (intracellular digestion). Other endoderm cells are able to secrete digestive enzymes into the large enteric cavity which digest the food so that it may be absorbed (intercellular digestion). The latter method of digestion is fundamentally the same as that which takes place in the alimentary tract of all the higher animals.

The endoderm cells, which are specialized for intracellular digestion, are somewhat larger than the epithelio-muscular cells of the ectoderm. Projecting from many of these cells into the enteric cavity are the flagella. Temporary projections of the cell, or pseudopodia, which appear to be similar to those in Amoeba, are also frequently formed. Both the flagella and pseudopodia apparently aid the cells in securing food particles for intracellular digestion. The internal structure of these cells varies somewhat, depending upon the amount of food which is present in the cell undergoing intracellular digestion. When plenty of food is present the cytoplasm contains a large number of gastric vacuoles. When food is not abundant, the gastric vacuoles are reduced in number and

large cavities appear in the cytoplasm. The glandular endoderm cells, which secrete the enzymes into the enteric cavity, exhibit no noteworthy structural modifications from those found in a typical animal cell. Interstitial cells are also found at the bases of the endoderm cells, next to the mesogloea.

B. LIFE PROCESSES

1. Nutrition

Hydra is chiefly a carnivorous animal, feeding upon a great variety of small, aquatic animals. These are first paralyzed by the nematocysts and then conveyed by the flexible, muscular tentacles to the central mouth opening. The ectoderm cells of the tentacles are able to secrete a sticky substance which aids in holding the captured prey. (B. f. 5.)

The food having been ingested, that is, passed through the mouth into the enteric cavity, the process of digestion begins. This may be either intracellular or intercellular, as noted above. It is probable that most of the food of Hydra is digested by the intercellular method. Thus to the endoderm cells is entrusted the nutrition of the entire Hydra, a condition which is typical of all the higher animal types. In the larger and more highly developed forms of animals a specialized transport tissue, the BLOOD, is necessary in order to carry the food absorbed from the alimentary canal to all the other cells of the animal body. In Hydra, however, this is not necessary, and the soluble food is passed along from cell to cell by diffusion through the cell walls.

A certain proportion of the material ingested by a Hydra consists of inorganic material which is not capable of being digested. These indigestible substances are egested from the enteric cavity to the exterior through the mouth opening. This is the only opening into the digestive cavity of Hydra, and it serves as a common opening for the ingestion of food and for the egestion of the refuse.

SYMBIOSIS. Among the several species of Hydra, the green colored species, *Chlorohydra viridissima*, is of particular interest from the standpoint of nutrition because of the fact that many of the endoderm cells of this species actually contain a great number of tiny, green plant cells belonging to the unicellular Alga, *Chlorella vulgaris*, which is closely related to *Pleurococcus* (p. 11). The cells of this plant give this species of Hydra its green color.

The interesting fact is that, although these plant cells are actually living in the cells of Hydra, they do not cause any harm to their host. On the contrary it appears that there is a mutual benefit derived from the partnership. A condition of this kind in which both organisms derive benefit from the association is known as SYMBIOSIS, and is to be distinguished from PARASITISM, in which one organism, the PARASITE, lives at the expense of another organism, the HOST. The benefit to the plant arises from the fact that some of the metabolic wastes of the Hydra are just what are needed for photosynthesis. On the other hand, as a result of the photosynthesis, an excess of oxygen is liberated, and this the Hydra secures for its own life processes. It is also probable that the Hydra makes use of any surplus food which may be manufactured by the plant cells. At any rate, experimental work has shown that, by placing green Hydras in certain environments it is possible to stop the food formation: the animals under such conditions become white, and, although they are able to survive, they do not show so great vitality as do other individuals in which the symbiotic condition is maintained.

2. *Respiration and Excretion*

There are no specialized organs of excretion in Hydra. Each of the cells apparently attends to the excretion of its own metabolic wastes just as the protozoan cells do. Respiration is carried on through the permeable cell walls and takes place both at the surfaces of the ectoderm cells, which are in contact with the surrounding water, and also at the surfaces of endoderm cells, which are in contact with the fluids of the enteric cavity.

3. *Reproduction*

Reproduction in Hydra may take place either asexually or sexually. The common asexual method is known as budding, and, as in *Grantia*, may often be observed in actively growing individuals. Certain cells in the body wall, generally near the basal disc, begin to divide rapidly and soon form a small swelling, which projects from the ectoderm. This projection continues to increase in size and soon shows a differentiation into the body proper and into the tentacles which surround a central mouth opening, and soon the bud resembles a small, attached Hydra. During the formation of the bud, both the body wall and enteric cavity of

the bud are continuous with the corresponding parts of the parent Hydra. A section through it shows that the body wall is made up of ectoderm, mesogloea, and endoderm surrounding a central enteric cavity, just as is the body wall of the parent Hydra. When the bud is fully developed the attachment with the parent Hydra is broken, a basal disc is developed, and the new individual begins an independent existence. (W. f. 57.)

In addition to asexual reproduction by budding it is also known that Hydra may reproduce by fission — that is, by a division of the entire animal into two individuals. The division is generally along the longitudinal axis, beginning at the distal, or tentacle, end of the animal and proceeding toward the foot. (W. f. 155.)

In connection with the asexual reproduction of Hydra, consideration should be given to the remarkable power of REGENERATION which this animal possesses. Regeneration may be defined as the ability of an organism to replace, or regenerate, missing parts in order to restore again the perfect whole. The power to regenerate lost parts varies greatly in different kinds of animals, but, in general, the ability exists in inverse ratio to the amount of cell specialization which is present. In other words, the higher the development of an animal, the less is its power of regeneration. Hydra is a comparatively simple type of Metazoön, and experiments on this organism have shown that it can be cut into several pieces — four or more and in many different planes, and each of these pieces will regenerate the missing parts in a short time. Thus, as a result of sectioning the animal and the power of regeneration which the tissues possess, there will be several individuals where previously there was only one. Regeneration in such cases really results in the asexual reproduction of the Hydra. (W. f. 158.)

SEXUAL REPRODUCTION. Under certain conditions which are not known, some species of Hydra develop male and female GONADS, both of which are temporary structures. Thus, the same individual may produce both sperm and eggs. In the higher animals, a single individual produces either sperm or eggs. An animal which produces both sperm and eggs is known as an hermaphrodite, as previously noted. (W. f. 154. C.)

The male gonads, or testes, in which the sperm are formed, develop as swellings in the ectoderm of the body wall, just below the tentacles. The testis consists of an outer covering of ectoderm cells which encloses a great number of the developing sperm cells.

The latter arise, as has been noted, from the interstitial cells of the ectoderm. By repeated divisions of the latter a very large number of immature sperm cells are formed. These undergo radical structural modifications, finally resulting in the formation of mature, free-swimming sperm which break forth from the gonad. They swim about freely in the water, and when one comes in contact with a mature unfertilized egg, it penetrates the egg membranes, thus permitting the permanent union of the male nucleus with the female nucleus, that is, fertilization, to occur. (W. f. 57, B.)

The ovaries of Hydra also develop as swellings in the ectoderm of the body wall, but these structures are located farther from the tentacles than are the testes. The eggs which are formed in the ovaries likewise develop from the interstitial cells. The process, however, is different from that which takes place in the formation of the sperm. In the first place there is usually only one egg formed in an ovary, whereas there are enormous numbers of sperm formed in a testis. In the early stages, an ovary of Hydra contains a large number of potential egg cells which have developed from the interstitial cells, but only one of these finally forms a mature egg cell, while the others aid in its nourishment. Some of the sister cells are actually engulfed by temporary pseudopodia which develop on the egg cell, and the latter becomes very large as a result of the nourishment supplied by the other cells. The egg, in its general shape and structure, is quite like a typical cell and very different from the atypical sperm cells. The large, mature egg projects through the ectoderm of the Hydra, covered only by a thin egg membrane, and there it awaits the sperm. It remains attached to the ectoderm at this point for some time even after fertilization has occurred. During later development it breaks away and becomes entirely free from the parent body. The sperm and eggs of any one Hydra do not mature at the same time and, therefore, the eggs are fertilized by sperm released from another individual. (W. f. 57, B.)

The process of fertilization in the egg of Hydra furnishes not only the method by which, as a result of the fusion of the chromatin material, the characteristics from two parents may intermingle, but also the stimulus for cell division. This is also true, in general, for all living organisms, including Man. Each starts its independent existence as a single egg cell which, when fertilized

by a sperm, begins to divide by mitotic cell division, the process being known as **CLEAVAGE**. As a result of cleavage, two cells, then four, eight, sixteen, etc., are formed. These cells remain attached to each other and, in *Hydra*, in a short time, when about 128 cells are present, it is found that they are arranged in the form of a hollow sphere, the wall of which is composed of a mosaic of cells closely fitted together. This stage in the development of *Hydra* or other forms is known as a **BLASTULA**, and it is broadly comparable with the permanent structure of *Volvox*, previously studied. (W. fs. 30, 31.)

In the development of *Hydra* the blastula is only a transient condition. The ectoderm cells, of which the wall of the blastula is composed, continue to divide and soon a special group of very active cells arises at one pole of the sphere. The latter are somewhat differentiated from the outer ectoderm cells, and they are destined to form the inner layer, endoderm, which, as will be remembered, lines the enteric cavity and is responsible for the nutrition of the animal. The young *Hydra*, in this two-layered condition, with outer ectoderm and inner endoderm, is known as a **GASTRULA**. After gastrulation the embryo forms a thin inner membrane and a thick, outer chitinous shell — both of which are products of the ectoderm cells — becomes free from the parent and falls to the bottom of the pond. Later the embryo emerges from the shell, develops tentacles, and the ectoderm and endoderm cells become specialized as in the mature *Hydra*. Thus *Hydra* remains essentially as a permanent gastrula made up of the two cellular layers, ectoderm and endoderm, separated by the non-cellular mesogloea.

Because of the fact that the body of *Hydra* and related forms is composed of two cellular layers, the ectoderm and endoderm, it is known as a **DIPLOBLASTIC** animal in contrast with the higher forms of **TRIPLOBLASTIC** animals, in which the body with the various organs arises from three original cellular layers, **ECTODERM**, **ENDODERM**, and **MESODERM**. In the triploblastic animals the very important and highly specialized layer of mesoderm lies between the ectoderm and endoderm. The ectoderm and endoderm of *Hydra*, together with the mesoderm of the triploblastic animals, are called the **PRIMARY GERM LAYERS**. In all forms of animals they arise very early in development by a differentiation of the embryonic cells, and it is by continued differentiation of the cells of these primary

germ layers that all the tissues and organs of the animal body are finally formed.

4. *Adaptation*

The simple nervous system which we have indicated in Hydra represents a great forward step in animal adaptation. Through this irritable and conductile tissue Hydra is able to receive external stimuli and to respond, or adapt, by the proper coördinated actions. It is, of course, apparent that all the cells in an animal must work together for the good of the organism as a whole or it cannot survive. It is the nerve tissue which governs this, unifying the various parts of an organism so that this indispensable condition is attained. Take, for example, locomotion in Hydra. This is brought about by means of a coördinated movement of the muscular elements in various parts of the body under the direction of the nerve cells. Locomotion takes place in several different ways: first, the Hydra may move by a slow, creeping movement in which the epithelio-muscular cells of the basal disc alone are involved; second, the Hydra may stand on its head, so to speak, and move along by a coördinated movement of its tentacles, or, finally, it may move like a 'measuring worm' by using both the basal disc and the tentacles. Whatever the type of locomotion, the actions of all the cells concerned are under the control of the nerve tissue, and the same is true for all the activities of the animal.

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IX. OBELIA

OBELIA is a marine animal and a typical representative of a considerable number of species of Coelenterate animals which exhibit the phenomenon of alternation of generations, or metagenesis, as this process is often called in animals. In Obelia, the life history includes a stage in which the organism consists of a colony of sessile, asexual individuals which are attached to a common stalk. This stage alternates with the medusa, or jellyfish, stage in which only independent, free swimming, sexual individuals occur. Among the various groups of Coelenterates wide variations in life history are found, ranging from a condition, as in Hydra, in which no medusa stage is known, to that in the true Jellyfishes, in which no adult stage comparable to Hydra occurs. Another noteworthy feature of many species of Coelenterates is the development of colonies of Hydra-like individuals as in Obelia, but with the formation of great amounts of secreted calcareous material between the individuals in the colony. Such is the case in the common Corals, several species of which are shown on page 53.

A. STRUCTURE OF THE ASEQUAL STAGE OF OBELIA

The general appearance of the asexual colonial stage of this animal is *superficially* plant-like. It consists of a colony of attached individuals, termed POLYPS, which are connected by a common stalk. The stalk is differentiated into two portions. There is, first, the part known as the HYDRORHIZA which is attached to some convenient solid object in the water, and, second, the branches, or HYDROCAULI, which arise from the hydrorhiza and bear the polyps at their tips. Both of these portions of the stalk are composed of an outer, transparent, exoskeletal sheath, the PERISARC, which is non-living, and an inner, living portion, the COENOSARC, which is continuous with the living material of the polyps. (W. f. 37, A: B. f. 9.)

The polyps composing a typical, fully-developed colony are of two kinds. There are, first, the NUTRITIVE POLYPS, or HYDRANTHS,

each of which, from a structural standpoint, may be regarded as comparable to an individual Hydra with a stalk attached, and, second, the REPRODUCTIVE POLYPS, or GONANGIA, which have become greatly modified for the purpose of asexual reproduction and are dependent upon the nutritive polyps for their nutrition.

The body wall of a hydranth is composed, like that of Hydra, of an outer layer of ectoderm and an inner layer of endoderm. Between these two layers there is a thin layer of the non-cellular mesogloea. Tentacles are present and surround a central mouth opening which leads into the enteric cavity. The living coenosarc, which is continuous throughout the colony, has the same structure as does the body wall of a polyp, and in fact it is to be regarded as a continuation of the ectoderm and endoderm. In other words, the bodies of the hydra-like polyps can be thought of as having become differentiated into an anterior portion, the hydranths proper, and a greatly elongated, posterior portion, the COENOSARC. Surrounding the entire colony is the non-living PERISARC, formed as a secretion by the ectoderm cells.

In a young colony of Obelia, all of the polyps are of the nutritive type, but, as a colony gets older, the gonangia are formed, which are specialized for the sole purpose of asexual reproduction. They are club-shaped and consist of an outer covering (GONOTHECA) which is a continuation of the perisarc, and an inner portion (BLASTOSTYLE) which is a continuation of the living coenosarc of the stalk. On this central, club-shaped blastostyle, a number of little swellings, the MEDUSA BUDS, appear, each of which develops, while still attached to the blastostyle, into a tiny jellyfish, or MEDUSA. When fully formed, the medusae become detached from the blastostyle, float out through an opening in the distal end of the gonotheca, and begin an independent existence.

B. STRUCTURE OF THE SEXUAL STAGE OF OBELIA

The sexual medusae of Obelia are very small, and resemble, in shape, a flattened dome or umbrella. The outer convex surface is called the ex-umbrella, or aboral, surface. Attached to the edge of the umbrella-shaped body are numerous tentacles. The under, concave surface of the body is called the sub-umbrella, or oral, surface. The opening on the oral surface is partly closed by a circular, perforated membrane, the VELUM, which is attached near the base of the tentacles. (W. f. 37, B, C; 38, B.)

Suspended from the center of the oral surface is the MANUBRIUM, which ends in a wide-lipped MOUTH. The lips are known as the ORAL LOBES. The manubrium, near its attachment to the oral surface of the body, merges into four RADIAL CANALS. These run at right angles to each other from the manubrium to the edge of the body near where the tentacles are attached, and there they connect with the CIRCULAR CANAL which encircles the body. The enteric cavity, which begins in the manubrium, is continuous throughout the radial and circular canals. The sexual reproductive organs, or gonads, are suspended from the radial canals, and are either male or female.

ECTODERM. The body wall of the medusa is similar in construction to that of all Coelenterates. It consists of an outer layer of ectoderm and an inner layer of endoderm. The two cellular layers are separated by the non-cellular mesogloea. The ectoderm cells form a covering over the entire body, including the oral and aboral surfaces and tentacles. The nematocysts are confined to the tentacles. The tentacles also bear a number of ADHESIVE DISCS which arise as modifications of the ectoderm cells.

The ectodermal nerve cells are more highly developed in a jellyfish than in Hydra, and both SENSORY and MOTOR nerve cells are present. In the ectoderm near the attachment of the velum, the nerve cells are grouped to form the NERVE RINGS. The latter encircle the body in the region near the circular canal. The cells of the nerve ring are chiefly motor in function. Two types of specialized SENSE ORGANS are formed in the ectoderm. At the base of each tentacle there is a spherical cavity containing pigmented ectodermal cells, while between the bases of the tentacles appear small, solid, ectodermal outgrowths, known as STATOCYSTS, which are believed to function as organs of equilibration. The peripheral sense organs are able to receive certain stimuli from the environment and pass an impulse on to the inner nerve cells. This is exactly what the sense organs do in the higher animals.

The stimuli received by the sensory cells are also able to bring about a high type of coördinated swimming movement. In swimming, there is a rhythmic contraction of the entire body brought about by the muscular elements present in the cells of both the ectoderm and the endoderm, under the control of the motor nerve cells. The contraction results in a decrease in the volume of the space between the velum and the top of the oral surface. A

portion of the water which fills this space is thus driven out with considerable force through the central opening in the velum. As a result, the animal is driven forward; that is, aborally, at each contraction. As soon as the water has been forced out the contraction ceases, the oral space again assumes normal size, and is filled with water as at first. These rhythmic, swimming movements in the medusa thus present a marked degree of coördination between the nerve and muscle elements.

ENDODERM and MESOGLOEA. The endoderm cells form the lining of the main enteric cavity in the manubrium as well as its continuation in the radial and circular canals. These cells have the same structure and function as in *Hydra*. The non-cellular, secreted mesogloea, lying between the ectoderm and endoderm, has the same general character in all Coelenterates, but in the medusa and other jellyfish a very much greater amount is present than in *Hydra*. It really forms the larger part of the body wall in these types; that is, the body wall may be said to consist of a thick layer of mesogloea, covered on the outside by a thin layer of ectoderm cells and on the inside by a thin layer of endoderm cells.

While at first glance one fails to observe any great similarity between the structure of *Hydra* and that of a free swimming jellyfish form, nevertheless, both are built upon the same fundamental polyp plan, and the various parts of the body occupy practically the same position in the two forms, the greatest difference between the two being the relatively large amount of mesogloea present in the medusa type. (W. f. 38.)

C. LIFE PROCESSES OF OBELIA

1. *Metabolic Processes*

In the attached, colonial stage of *Obelia*, the processes of nutrition, respiration, and excretion are so nearly like those of *Hydra* that no special description is necessary. Any surplus of food from the nutritive polyps goes by way of the coenosarc to the support of the colony as a whole, particularly for the development of the stalk and the reproductive polyps.

In the free-swimming medusae there are certain methods of food capture which should be noted. The jellyfish secures its food in two ways. When it is moving through the water, the food which comes in contact with the tentacles is captured and conveyed to

the mouth by them. These tentacles, owing to the sensory nerve cells which are scattered through the ectoderm, are very sensitive to stimuli, and small animals which come into contact with them bring about a quick response. There is an explosion of the nematocysts, and the prey, paralyzed by the poisoned stinging hairs, is conveyed to the mouth by the tentacles.

The jellyfish, when not swimming, sinks to the bottom and lies with the oral surface up. In this position the tentacles and the oral lobes of the manubrium are able to secure any bits of food that may fall on them from the surface of the water. For example, bits of clam meat may be dropped on the animal, and their capture and ingestion easily seen. Any food secured by the animal is taken into the enteric cavity through the mouth. Digestion as in *Hydra* occurs both by intracellular and intercellular methods. A portion of the food passes from the enteric cavity, or 'stomach,' at the base of the manubrium, through the radial and circular canals where it is absorbed, and thus the entire organism is nourished.

2. *Reproduction*

The reproduction of the colonial *Obelia* is entirely asexual, and may take place either by a general growth of the hydrorhiza or by the formation of numerous medusa buds in the gonangia.

In the first type of reproduction mentioned, the hydrorhiza of an *Obelia* colony grows along the substratum to which the colony is attached. At certain intervals erect hydrocauli, which bear the hydranths, are formed from the hydrorhiza. The nutritive polyps thus formed furnish an additional supply of food material so that the hydrorhiza can continue to grow.

In the formation of medusa buds, *Obelia* exhibits a highly interesting type of asexual reproduction which leads directly to the consideration of the phenomenon of alternation of generations, inasmuch as the free-swimming medusae, produced in the reproductive polyps by asexual budding, develop into sexual individuals possessing either ovaries or testes. The gonads of either sex are attached, as previously stated, to the radial canals of the medusa, and no external morphological differentiation is to be noted between the two sexes. When sexually mature, the eggs break out of the ovary of a female medusa directly into the sea water. Similarly, from the testes of a male, active sperm are liberated. These swim freely through the water to the eggs, and fertilization, followed by

cleavage, occurs as in *Hydra*. The result of the first stages in development is the formation of a tiny, ciliated larva, known as the *PLANULA*. The planula swims around for a time, then becomes attached to some suitable solid material in the water and soon begins to change its form and to develop into the attached, colonial asexual phase of *Obelia* with which we began the study of the life history. (W. f. 37.)

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X. STARFISH

IN the previous chapters on Hydra and Obelia, mention was made of the radial symmetry exhibited by these forms. Nature's experiments with this plan of animal organization apparently reached its climax in the phylum Echinodermata, a typical representative of which is to be found in the Starfish. The Coelenterates and Echinoderms were, for a long time, placed in the same group, which was known as the Radiata, but later it became evident that they should be placed in separate phyla.

As a matter of fact it is generally believed that the radial symmetry of the adult Starfish and other Echinoderms has a more or less superficial character for, in the embryonic condition of these animals, the body plan is not radial but two-sided, that is, a right- and left-sidedness, a condition known as BILATERAL SYMMETRY. As will be noted in the following chapters, bilateral symmetry is common to practically all the higher types of animals. Considered from various standpoints the Echinoderms appear as an atypical group and one which presents many difficulties with respect to their true relationships.

The Starfish presents, as will be seen from the description below, a much higher degree of differentiation and complexity in its general structural features than do the animal types heretofore studied. And for the most part it is difficult to relate these Starfish structures with those present in other animal groups. In other words, we have here an animal exhibiting a number of interesting and complex features which clearly are off the beaten track of animal organization. In correspondence with the unusual structural features are various functional adjustments, some of the most interesting of which are centered around the water vascular system.

A. EXTERNAL STRUCTURE

The body of the Starfish consists of a central, circular DISC from which five, pointed ARMS radiate. Practically the entire surface of the body is covered with a thin, ciliated epidermis, underneath which is a heavy body wall, studded with blunt, projecting, cal-

careous spines, around the base of which numerous tiny PEDICELLARIAE are grouped. Structurally and functionally the pedicellariae resemble a pair of pincers, and they are able to seize and to hold minute objects when contact is made. They function primarily, it is believed, in keeping the body surface free from foreign materials which might be injurious to the delicate, respiratory BRANCHIAE. These are tiny filamentous projections of the inner tissues which are found in considerable numbers in the areas lying between the spines and the surrounding pedicellariae. The central cavity of each branchia is continuous with the general body cavity, and is filled with body fluid. The branchiae function in respiration by the exchange of respiratory gases through their thin walls. (W. f. 46.)

Turning our attention to the central disc, a small, circular, perforated plate, the MADREPORITE, is to be seen lying in the area of the disc between two of the arms. The madreporite is the external opening into the WATER VASCULAR SYSTEM, a unique feature of Echinoderm structure which is described below. Near the center of the disc is a minute ANAL OPENING which is practically non-functional, as will be shown later. The two arms projecting from the central disc on either side of the madreporite are designated the BIVIUM, while the other three arms constitute the TRIVIUM.

Considering the Starfish from the under, or ORAL, surface, the MOUTH will be found opening in the center of the disc, surrounded by five groups of movable spines. Very prominent features are the five AMBULACRAL GROOVES which run from the mouth to the tip of each arm. Throughout the entire length of each ambulacral groove are numerous projecting muscular elements, the TUBE FEET, which constitute the chief structures of the water vascular system for locomotion and the capture of food.

STRUCTURE OF THE BODY WALL. The body wall of the Starfish contains many flat, articulating skeletal structures, the calcareous plates, or OSSICLES, on which the projecting spines rest. Between the ossicles, which in most regions of the body are irregularly arranged, there are resistant connective tissue elements and muscle fibers which form a common 'cement substance.' On the under surface of the arms, the regularly arranged and specialized ossicles form the walls of the ambulacral grooves in which the tube feet are located. In the roof of the ambulacral grooves, the arrangement of the double row of ambulacral ossicles is such that the opening of

the groove can be entirely closed and protection thus offered to the enclosed tube feet.

B. ORGAN SYSTEMS

1. *Nutritive System*

The nutritive system of the Starfish, conforming to the general structural plan of this unique organism, is quite unusual in various structural features. The MOUTH, as has been noted, is centrally placed on the under surface of the central disc and opens into a short tube, the ESOPHAGUS. The latter continues upward (aborally) and leads into a large, five-lobed, thin-walled sac, the STOMACH, which occupies most of the space in the central disc. The oral, or cardiac, portion of the stomach is so constructed that it can be pushed out, or everted, through the mouth opening when the animal is feeding. From the somewhat smaller pyloric portion of the stomach, which lies above the cardiac portion, five pairs of PYLORIC CAECA arise; each pair extending into and throughout the entire length of an arm. The caeca branch extensively to form a great number of lateral pouches in which the digestive enzymes are secreted. A tiny intestinal tube, the RECTUM, also has its origin in the pyloric portion of the stomach from which it continues to the very small anal opening on the aboral surface of the central disc.

When the animal feeds, the cardiac portion of the stomach is everted through the mouth opening, and, wrapping itself around the food material, proceeds to digest it outside the body. Indigestible materials taken into the digestive system are later egested via the mouth so that very little, if any, use is made of the intestine in this connection. The digested food is absorbed by certain of the cells lining the alimentary tract, then passed on to the outer cellular layers, and finally transferred to a body fluid (COELOMIC FLUID) present in the body cavity (COELOM). The latter surrounds the stomach and continues into each arm, so that the food materials picked up by the coelomic fluid are distributed to all parts of the organism. The movement of the fluid throughout the body spaces is more or less irregular, but it is aided by the action of ciliated cells present in certain areas of the lining of the coelom.

2. *Water Vascular System*

The echinoderm water vascular system is unimitated, nothing comparable being found in any other group of animals. It consists of a complex system of closed tubes which may be said to begin

with the perforated calcareous MADREPORITE situated on the aboral surface of the central disc. From the madreporite a tube, the STONE CANAL, runs orally toward the mouth, in which region it connects with the RING CANAL, encircling the mouth. From the ring canal, five RADIAL CANALS lead off—one following the roof of the ambulacral groove to the tip of each arm. From the inner surface of the ring canal nine tiny sacs (TIEDEMANN'S BODIES) project toward the mouth. In them, amoeboid cells are formed which probably function in excretion. Throughout the length of each radial canal, many minute paired branches arise to which the tube feet are attached.

Each of the hollow, muscular tube feet is provided with the bulb-like portion, the AMPULLA, which lies above the roof of the ambulacral groove in the body cavity. The body of each tube foot proper extends orally and projects to the exterior through a tiny opening between the ambulacral ossicles, where it ends in a circular suction disc. The latter is a very important feature because it can be pressed against almost any solid object, and the contact maintained by suction. It is by such action that food is secured and locomotion performed.

We may now consider certain important features connected with the functioning of this extraordinary system. Water is drawn into the water vascular system through the madreporite, it is believed, by the action of ciliated cells lying within the madreporite, and it fills the various canals and the ampullae of the tube feet. When it is necessary to extend the tube feet, the muscular walls of the ampullae contract and thus force the water down into the body of each tube foot, and this results in its enlargement and extension. A tube foot thus forced into contact with a solid object adheres through the action of the suction disc noted above. Release of the tube feet is brought about by a reverse flow of water into the ampulla. When a considerable number of tube feet thus become attached to an immovable object, a slow creeping movement of the entire organism can be effected by a coördinated contraction and shortening of the tube feet alternating with their release and a subsequent reëxtension and attachment in an advanced position.

In feeding, the tube feet of an arm may be applied and attached to a piece of food and the latter gradually moved to the mouth by the action of the tube feet alone or by the coördinated bending action of the arm.

3. *Respiratory, Excretory, and Vascular Systems*

It has been emphasized repeatedly that the processes of respiration and excretion must be continuously in operation in every living cell. In a larger and more complex type of animal, like the Starfish, it is necessary that arrangements be made so that the oxygen necessary for respiration can be supplied to those cells of the body which are not in contact with the surrounding water, and in addition, so that the carbon dioxide and other metabolic wastes can be removed. In other words a specialized transportation system is essential. This function is performed in the Starfish by the coelomic fluid which flows through the tissues and serves as a general transportation system for the materials passing between the cells and their environment. Present in the coelomic fluid are numerous isolated amoeboid cells, the AMOEBOCYTES, which are formed from the tissue lining the coelom.

In types of animals higher than the Starfish, such, for example, as will be seen in the Earthworm, the much more complex VASCULAR SYSTEM with the blood circulating through the body in closed tubes, the blood vessels, performs essentially the same function. It is the link between the cells and their environment. As a matter of fact, in the Starfish, the possible forerunner of the closed vascular system of the higher animals is to be found in the so-called PERIHEMAL SYSTEM, the tiny tubes of which run, for the most part, parallel with and just below those of the water vascular system. The perihemal tubes contain a small amount of fluid which possibly is of the same nature as the blood of higher animal types.

With regard to the exchange of gases essential to respiration, the pertinent facts may be stated as follows: The carbon dioxide picked up by the coelomic fluid from the cells with which it comes into contact is carried to the tubular DERMAL BRANCHIAE which, as has been noted above, project through the body wall into the surrounding water. The respiratory exchange is carried on through the walls of the branchiae, the oxygen received passing in turn to the tissue cells as the coelomic fluid is slowly moved throughout the body, largely by ciliary action.

In the excretion of nitrogenous wastes, it appears that the wastes from the cells pass into the coelomic fluid, then are carried to the RECTAL CAECA through which they leave the body. The rectal

caeca are two tiny secreting bodies which open into the intestine, so that the nitrogenous wastes leave the body through the anus. It has already been noted that the intestine does not function for the egestion of material from the alimentary canal. It is also commonly stated that the amoebocytes function as excretory agents in that they ingest various types of solid waste materials. Later these amoebocytes pass through the thin walls of the dermal branchiae and leave the body permanently.

4. *Reproduction*

Unlike the hermaphroditic condition noted in *Hydra*, the sexes are separate in the Starfish. No external differentiation between the two sexes is to be noted, and, as a matter of fact, there is very little internal structural differentiation except during the breeding season, for the gonads in both sexes are very small during the remainder of the year. In sexually mature animals, in the spring of the year, the gonads of both sexes gradually attain full size and then they fill up a considerable portion of the body cavity in the central disc and extend out into each arm for a considerable distance. The ripe germ cells leave the body through tiny GENITAL PORES on the aboral surface of the body — one of which is located near the base of each arm. The fertilization of the Starfish eggs occurs in the surrounding water, and the zygote rapidly develops into a free-swimming, ciliated embryo which is definitely bilateral for a time and then gradually changes into the radially symmetrical adult condition.

5. *Nervous System*

Our previous study of *Hydra* revealed the presence of a nerve net composed of numerous interconnected nerve cells widely distributed throughout the ectoderm layer. In the Starfish there are many such nerve cells with wide distribution, and, in addition, a more highly developed and definite nerve tissue is found in which the constituent elements are grouped to form radiating nerve fibers of various lengths. This central nervous system of the Starfish consists essentially of a NERVE RING surrounding the mouth below the ring canal and, in each arm, a fine nerve fiber which, beginning at the nerve ring, runs to the tip of the arm where it ends in a primitive pigmented EYE SPOT. From the nerve ring and the nerve fibers in each arm many small branches

are given off which innervate all the interior organs. The innervation of the animal is so complete that the muscle tissue in the walls of every one of the tube feet receives its own tiny branch. It can be shown experimentally that the nerve center which controls all the muscular action is located in the nerve ring, for when it is cut the movements of the animal become erratic and purposeless.

The locomotion of the Starfish, involving, as it does, the slow expansion and contraction of great numbers of tube feet, is very slow. Very different is this function in the Brittle Star (*Ophiura*), figured on page 53. The long, flexible arms of *Ophiura* are supplied with heavy muscles which, under the control of the nervous system, move the arms so as to cause rapid locomotion.

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XI. EARTHWORM

THE Earthworm, of which there are a great many species widely distributed in the soil of practically every region of the globe, belongs to a phylum of segmented animals known as the Annelida. Due to the fact that the Earthworm possesses a number of structural features which are of considerable importance in interpreting those of still higher types of animal life, it is an especially valuable form for study. These structural features may be enumerated as follows :

(1) The Earthworm is a triploblastic animal ; the three primary germ layers, ectoderm, mesoderm, and endoderm, being present as in higher animals, and in contrast to diploblastic animals like Hydra.

(2) The Earthworm possesses a body cavity, or coelom, lying between the body wall and the tubular alimentary canal. Thus, the body plan may be described as a tube within a tube. This type of structure is present in higher forms, but it is not found in the Coelenterates, in which the body may be said to consist of a single tube.

(3) The Earthworm shows a definite segmentation, or metamerism of the body ; that is to say, the body is composed of a large number of distinct segments which are arranged in a linear series. Varying degrees of segmentation are present in most of the higher forms of animals.

(4) The Earthworm shows a two-sided, or bilateral, symmetry. As a rule, the organs in such a case are paired : one situated on the right side of the body and one on the left side. Accordingly there is only one plane which will divide the animal into symmetrical halves. Bilateral symmetry is even more pronounced in the higher animal types.

(5) The Earthworm possesses a number of highly developed organ systems for performing various vital functions, such as nutrition, transportation, excretion, etc. These arise by a grouping of certain tissues, and are characteristic of all the higher organisms.

A. EXTERNAL STRUCTURE

The Earthworm has an elongated, cylindrical, segmented body which may vary in length from a few inches to a foot or more. Rare species of Earthworms are known which may even reach a length of several feet. One end of the body tapers down to a somewhat blunt point in contrast to the opposite end, which is rather flattened. A study of the animal shows that the more pointed end is the anterior, or head, end, and the opposite is the posterior, or tail, end. The Earthworm may be said, therefore, to show **ANTERO-POSTERIOR DIFFERENTIATION**. Also, the worm, when crawling along, maintains as a general rule the same part of the body in contact with the solid surface. An examination of the body will show that this lower, or ventral surface, on which the worm crawls, is somewhat flattened as compared with the upper, or dorsal surface. A differentiation between these two surfaces, as shown in the Earthworm, is known as **DORSO-VENTRAL DIFFERENTIATION**.

The number of segments present in the body varies considerably in individual worms, but all the segments have essentially the same structure. Certain minor segmental variations may be noted. The first segment at the anterior end of the body has an overhanging dorsal projection, known as the **PROSTOMIUM**, which forms a lip-like structure over the mouth. In the last segment of the body is the slit-shaped **ANAL** opening. About one-fourth of the distance back from the anterior end a few segments are differentiated to form an enlarged glandular structure, termed the **CLITELLUM**, which functions in connection with reproduction. (W. fs. 59; 60.)

If an Earthworm is drawn through the fingers a roughness will be noted. This is due to the presence in each segment of tiny bristles, or **SETAE**, which project through fine openings in the body wall. Each segment has eight setae arranged in four pairs. The setae are in corresponding positions in each segment, so that four double rows of setae are formed which run the entire length of the body. Two of the double rows are on the ventral surface: one double row is on the right, and one on the left side.

In a transverse section of the body, the finer structure of the setae may be observed. Each consists of a bristle embedded in the body wall, long enough to project a slight distance beyond the exterior surface of the body at one end and, at the other end, to

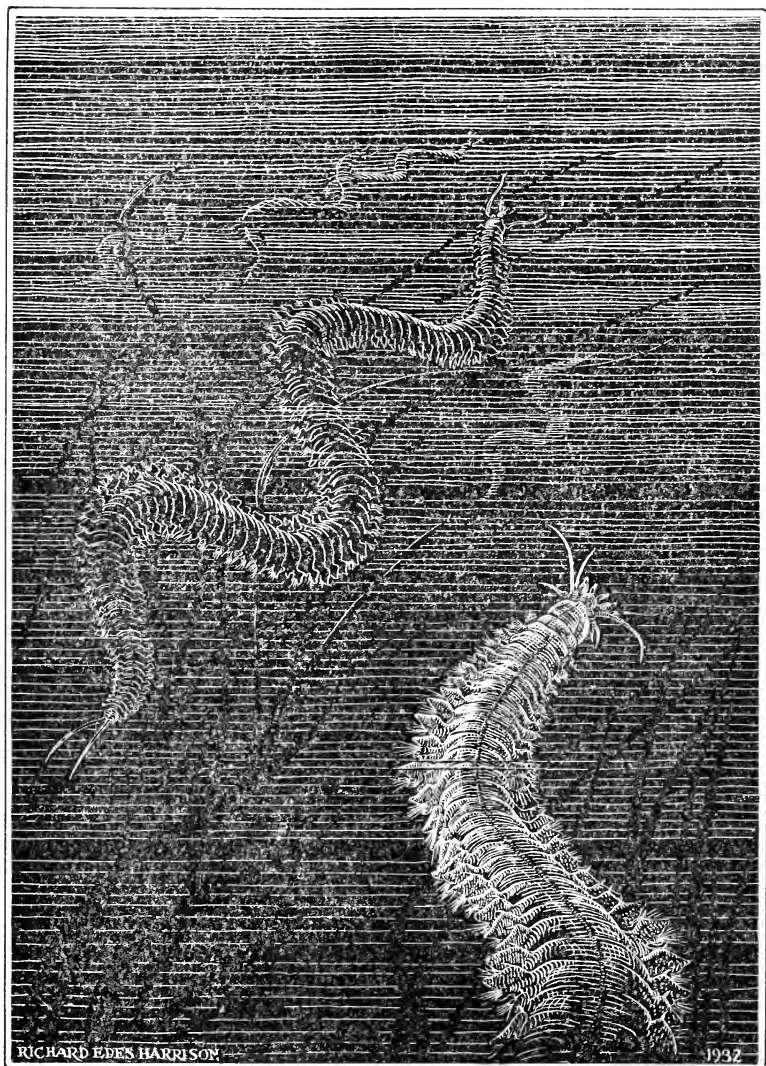


FIGURE 6

The Annelida include a large subclass of marine worms, the Polychaeta, of which the Sandworm (*Nereis virens*), here shown, is a well-known example. The marine worms possess paired, muscular organs, the parapodia, which function in locomotion and respiration. *Nereis* and many other related forms are vigorous swimmers. Many species are found, however, which are tube dwellers with degenerate or modified parapodia. The development of the head region, particularly with regard to sensory structures, is also a noteworthy feature of the Polychaets.

project into the coelomic cavity. The basal end of each seta is covered over by a number of muscle fibers which are attached to the near-by body wall. The arrangement and attachment of the muscle fibers to the setae is of such a nature that the ends of the setae, which project externally through the body wall, can be pointed either anteriorly or posteriorly by a contraction of the proper fibers. This permits of their use in locomotion. (W. f. 61.)

B. ORGAN SYSTEMS

It has been noted that the body plan of the Earthworm may be described as a tube within a tube; the outer tube being the body wall, the smaller enclosed tube the alimentary canal, and the space between the body wall and the alimentary canal constituting the body cavity, or coelom. A study of the embryonic development of the Earthworm shows that the coelom is formed by a splitting of the mesoderm into an outer layer, which is in close contact with the outer ectoderm and forms the main portion of the body wall, and an inner layer, which is in close contact with the functional endoderm of the alimentary canal. Thus the coelom is completely lined with mesoderm. The coelom develops in essentially the same way in all higher types and, although subject to considerable structural variation, it is an important feature of the triploblastic animals, and particularly so in the Vertebrates.

The coelom of the Earthworm is not a single open space running from the anterior to the posterior end of the body, but is divided into as many compartments as there are segments in the body. These divisions of the coelom are due to membranous dividing walls, or SEPTA,¹ which are attached both to the body wall and to the alimentary canal. Each of the segmental grooves, which can be seen on the external surface of an Earthworm, marks the attachment of a septum to the body wall. (W. f. 59, A, B, C.)

STRUCTURE OF THE BODY WALL. A microscopical examination of a prepared transverse section through the body wall of the Earthworm shows the following arrangement of tissues. (W. f. 61.)

The outer layer consists of a very thin, transparent membrane, known as the CUTICLE. This is not a cellular layer, but is formed as a secretion by the EPIDERMAL CELLS which lie directly underneath. Most of the epidermal cells contain pigment, especially those on the dorsal side of the animal, with the result that this

¹ Singular, septum.

region of the animal is somewhat darker. Certain epidermal cells secrete mucus which passes out through openings in the cuticle and covers the body. Sensory cells are also present in the epidermis. The next layer of the body wall consists of CIRCULAR MUSCLE TISSUE. This tissue is formed from a great many long, spindle-shaped muscle cells which are so arranged that when they contract the diameter of the body is decreased. Beneath the circular muscle layer is a thick layer of LONGITUDINAL MUSCLE TISSUE in which the cells are arranged with their long axes parallel to the long axis of the body so that when they contract they cause a decrease in the length of the animal. The innermost layer of the body wall is known as the COELOMIC EPITHELIUM. It consists of flattened epithelial cells which form the lining of the coelom.

1. *Nutritive System*

Beginning with the mouth opening at the extreme anterior end of the body, the alimentary canal continues as a straight tube throughout the entire length of the animal and finally ends at the anal opening situated at the extreme posterior end. The following regions may be noted. (W. f. 60.)

The PHARYNX extends from the mouth through segment vi. It is a heavy-walled, spindle-shaped structure and is attached to the body wall by a great many fine muscle fibers.

The ESOPHAGUS begins at the posterior end of the pharynx in segment vii and continues posteriorly as a narrow, straight tube to segment xiv, where it connects with the crop and gizzard. Paired swellings on the sides of the esophagus in segments x-xiv constitute the CALCIFEROUS GLANDS.

The CROP and GIZZARD constitute sac-like enlargements of the alimentary canal lying between segments xiv and xix. Although of about the same size and shape, these two organs differ considerably in structure. The crop is thin-walled and elastic and serves for the temporary storage of food, whereas the gizzard has heavy, muscular walls, and is adapted for grinding the food.

The INTESTINE has its beginning at about segment xx and continues as a straight, tubular structure to the posterior end of the body, where it ends at the anal opening. In each segment there is a slight out-pouching of the intestinal wall.

The structural features of the intestine as revealed by the microscopic study of a transverse section may now be described. The

intestine is roughly circular in outline with a large central cavity. The latter is partly filled by an infolding of the dorsal wall to form the **TYPHLOSOLE**, which greatly increases the effective absorptive surface. The outer surface of the intestine and the interior of the typhlosole is covered by layers of long, cylindrical cells, composing the **CHLORAGOGEN LAYER**. These cells are believed to have an excretory function, and the yellowish green pigment granules scattered through their cytoplasm are regarded as metabolic wastes which they have removed from the blood. The mass of chloragogen cells continues into the typhlosole and, indeed, forms the greater portion of this structure. (W. f. 61.)

Lying just within the chloragogen tissue is a layer of circular muscle tissue which forms a band running entirely around the intestine. Just as in the body wall, the contraction of the muscle fibers of this layer brings about a reduction in the diameter of the alimentary tract. Numerous bundles of muscle fibers, running lengthwise of the alimentary canal, lie below the circular muscular layer. They do not form so definite a layer as the circular muscles, since they are arranged somewhat irregularly. Numerous blood vessels are present in the muscle tissue of the intestine and, between the two layers, blood spaces are found in which the blood receives the absorbed food materials.

The innermost layer of the alimentary canal, known as the **LINING EPITHELIUM**, is composed of endoderm cells which are responsible primarily both for the digestion of the food material and its absorption after it has been digested. There are, in fact, two types of these endoderm cells: the gland cells and the absorptive cells. The gland cells secrete digestive ferments, or enzymes, which are comparable to those present in other animal forms, and these have the power to change, or digest, the food so that it can be absorbed. The gland cells vary considerably in size and shape, depending upon the amount of material they contain. The absorptive cells are quite regularly arranged between the gland cells, and are adapted for absorbing the digested food material from the cavity of the intestine and transferring it to the blood stream for transportation to all parts of the body. The bodies of the absorptive cells are quite large, and the free ends are ciliated.

FUNCTIONAL. The Earthworm, as its name indicates, is adapted for living in the soil. The holes, or burrows, which it makes, vary in depth from a few inches to several feet, depending upon the

nature of the soil. In all cases, the burrows are formed by the Earthworm literally 'eating a hole' in the soil. All the materials taken from the burrow pass into the alimentary canal through the mouth opening, then through the entire length of the canal, and finally are egested through the anal opening as castings, or feces. The castings are voided at the surface around the entrance to the burrow, where they form tiny mounds of earth. The great number of Earthworms present in the soil of many regions, together with their habit of almost continual burrowing, makes it possible for them to bring considerable quantities of soil from lower depths to the surface. It has been estimated that in some localities as much as 18 tons of soil per acre are annually brought to the surface in this manner.

This method of burrowing by eating through the soil not only provides the Earthworm with a method of home-building, but it also constitutes the chief source of its food supply, for, as the soil passes through the alimentary canal, much of the organic material there present is utilized for food. In addition to obtaining food from the materials in the soil, the Earthworm when it comes to the surface, generally at night, secures various other materials which can be utilized for food.

In the ingestion of food material the pharynx plays an important part. When the mouth is applied to some suitable object, the muscle fibers, which run from the pharynx to the body wall, contract. This enlarges the pharynx, and the resulting suction aids in drawing the food through the mouth and into the pharynx. The ingested material passes through the pharynx and esophagus. In the latter, a secretion from the calciferous glands, consisting largely of calcium carbonate, is added to the food, which probably aids in neutralizing any excess acidity which may be present. The material passes next into the crop, which serves only as a temporary storage place, and then into the muscular gizzard, where it is ground. Finally, the ingested material is passed into the tubular intestine and as it moves slowly through this part of the alimentary canal, the cells of the lining epithelium carry on the digestive and absorptive processes as noted just above.

2. *Vascular System*

In the Earthworm there is a closed vascular system which has as its function the transportation of various kinds of materials

to all regions of the body. Such a system forms a necessary part of the structure of all the higher forms of animals. It consists of (a) a circulating medium, the **BLOOD**, which is adapted for transporting the various materials, and composed of a fluid portion, the **PLASMA**, containing an enormous number of isolated living cells, the **BLOOD CORPUSCLES**. (b) The blood is contained in a system of connected, closed, muscular-walled tubes, the **BLOOD VESSELS**. (c) Contractile portions of the blood vessels, **HEARTS**, drive the blood through the vessels by means of rhythmical muscular contractions. There is also present in such types of circulatory systems, (d) numerous blood spaces permeating the tissues, by means of which the fluid portion of the blood can come into direct contact with the living cells of the tissues. The vascular system exhibits a high degree of development and complexity, as will be evident from the following description.

(1) **LONGITUDINAL VESSELS**. There are five blood vessels which run the length of the body. The largest of these is (a) the **DORSAL VESSEL** which lies on the dorsal side of the alimentary canal. Ventral to the alimentary canal in the same relative position is (b) the slightly smaller **VENTRAL VESSEL**. These two vessels are directly connected by five pairs of heavy walled contractile heart-like vessels (c) the **AORTIC LOOPS**, which lie in the anterior end of the body in segments viii to xii. The other three longitudinal vessels are considerably smaller and lie near the ventral body wall in close association with the nerve cord. These are (d) the important **SUBNEURAL VESSEL**, lying ventral to the nerve cord, and (e) the two smaller **LATERAL NEURALS**, situated to the right and left of the nerve cord.

The Dorsal Vessel is the chief collecting vessel and, posterior to segment xii, receives blood in every segment from the various segmental vessels noted below. Anterior to segment xiii it is a distributing vessel and gives off the collected blood to the aortic loops and to the tissues of the pharynx where it ends.

The Ventral Vessel is the chief distributing unit of the vascular system and throughout its length gives off the blood received from the aortic loops to the connecting segmental vessels.

The Subneural Vessel receives blood at the anterior end of the body from small branches and distributes it throughout the length of the body by means of segmental vessels which connect with the dorsal vessel, as noted below.

The Lateral Neural Vessels receive blood from the anterior end of the body and distribute it to the nerve cord throughout its length.

A pair of short longitudinal vessels, the EXTRA-ESOPHAGEAL, is present in the anterior end of the body, one on either side of the esophagus. They arise by small branches in the pharyngeal region and extend posteriorly through segment xii. The blood collected anteriorly is carried back to segment xii, where connection is made with segmental vessels leading to the dorsal vessel.

(2) SEGMENTAL VESSELS. In each segment of the body, posterior to the aortic loops, small vessels connect with the larger longitudinal vessels. These segmental branches carry blood to and from the many tissues and organs of the body. The principal segmental vessels are as follows:

(a) The Dorso-subneural vessels which, branching from the subneural vessel, run dorsally along the septa and empty into the dorsal vessel. Enroute they collect blood from the body wall and the nephridia.

(b) The Dorso-intestinal vessels which collect blood from the tissues of the intestine and carry it to the dorsal vessel.

(c) The Ventro-intestinal vessels which distribute to the tissues of the intestine the blood received from the ventral vessel.

(d) The Ventro-parietal vessels which distribute to the body wall, nephridia, and reproductive organs the blood received from the ventral vessel.

COURSE OF THE CIRCULATION IN THE EARTHWORM. The general course of the blood flow through the body is as follows. Starting at the posterior end of the worm and continuing anteriorly to the aortic loops, blood is received into the dorsal vessel from the various segmental vessels (dorso-subneural and dorso-intestinal). The blood is forced anteriorly by rhythmic waves of contraction, or PERISTALSIS, in the muscular walls of the dorsal vessel, which begin at the posterior end of the vessel and move anteriorly in a regular manner. At the anterior end of the body a large proportion of the blood flows into the aortic loops which contract synchronously with the dorsal vessel and force the blood into the ventral vessel. Valves are present in the aortic loops, which prevent a back-flow into the dorsal vessel. The main flow in the ventral vessel is posterior, although a small amount in the region of the aortic loops is forced to the extreme anterior end of the body. The ventral vessel is not contractile, so the flow of blood

in it is due to the pressure induced by the contractions of the aortic loops. As the blood moves posteriorly in the ventral vessel it is forced out into the segmental vessels (ventro-intestinal and ventro-parietal) which convey it to the various important organ systems where connection is made with tiny connecting vessels, the CAPILLARIES, leading to the dorsal vessel, as noted above.

In the region of the aortic loops and anterior thereto, both the dorsal and ventral vessels distribute blood to the various tissues. This is collected and returned to the dorsal vessel by either the extra-esophageal vessels or the subneural vessel in association with the dorso-subneurals. Thus the circuit is complete.

In the above description of the circulatory system, emphasis has been placed upon the various closed vessels. As a matter of fact, if the circulatory system consisted only of the closed tubes, it would fail to function in supplying the needs of the cells. So all through the tissues there are blood spaces in which this blood fluid, finding its way through the thin-walled capillaries, actually comes into contact with, and bathes, the cells. In this way the interchange of materials between the blood and the cells takes place.

In addition to the 'closed type' of circulation of blood by means of the regular vascular system, the Earthworm has an 'open type' of circulation in the coelom. The latter contains the COELOMIC FLUID, which is closely affiliated with the blood in its composition and in its functions. The various movements of the worm bring about contractions of the body, with the result that the coelomic fluid, from time to time, is forced back and forth through openings in the septa, thus bathing the tissues with which it comes into contact.

3. *Respiratory System*

The blood carries to the cells not only the food absorbed from the intestine, but also oxygen which, as we know, is absolutely necessary for the metabolic activities. Also the blood carries the metabolic wastes, both liquid and gaseous, away from the cells to the proper excretory organs. The gaseous interchange, in which carbon dioxide is given off and oxygen is obtained, occurs at the surface of the body. The body wall, which is normally kept moist through the mucus secreted by gland cells in the outer epidermis, is also richly supplied with the capillaries, and the blood passing into the body wall comes into close contact with the oxygen of

the external environment. There is also good evidence that the highly vascular calciferous glands relieve the blood of considerable quantities of carbon dioxide which they excrete into the alimentary canal. It should be clearly understood that the essential part of respiration is the interchange of oxygen and carbon dioxide by every cell in the body. The carrying of these gases to and from the body surface by the blood is a necessary mechanism of respiration. The blood plasma of the Earthworm is colored red by a complex, oxygen-carrying compound, HEMOGLOBIN, which is dissolved in it.

4. *Excretory System*

The Earthworm has an important system for the excretion of the liquid metabolic wastes of the body, consisting of numerous tiny coiled tubes, known as NEPHRIDIA.¹ Except in the first three or four segments there are two nephridia present in each segment of the body. They lie in the coelom, below the alimentary canal, and close to the ventral body wall through which they open. In each segment one nephridium lies to the right and one to the left of the mid-ventral line. (W. fs. 59, C; 60.)

Each nephridium consists of the following parts: (a) A ciliated, coelomic opening, the NEPHROSTOME; a long, greatly coiled tube which lies in three loops and consists of (b) a long, very narrow, thin-walled portion leading from the nephrostome, and (c) a larger, tubular region, of considerable length, which continues through the ventral body wall to the external opening, or NEPHRIDIOPORE. A nephridium does not lie entirely in one segment, but the nephrostome and a small portion of the fine connecting tubule penetrate the posterior septum of the segment just in front. (W. f. 128, a, b, c.)

It is probable that most of the metabolic wastes of the tissues accumulate in the coelomic fluid. These wastes may be drawn into the lumen of a nephridium by the action of the ciliated nephrostomal cells and then passed the length of the tubular portion and through the nephridiopore to the exterior. Or, again, the wastes may be removed from the coelomic fluid, which bathes the nephridia, by the direct absorptive action of specialized cells located in the middle region of the nephridia, which then secrete the wastes so removed into the central lumen for passage to the exterior.

¹ Singular, nephridium.

Wastes from the blood, present in the tiny vessels running to the nephridia, may also, perhaps, be removed to some extent by the nephridial cells, but it appears clear that the chloragogen cells, which come into intimate contact with the blood in the intestinal vessels, are the most important excretory agents of the blood. It is usually held that such wastes eventually find their way into the coelomic fluid through the disintegration of the chloragogen cells, although some authorities have concluded that the wastes remain permanently in these cells.

5. *Reproductive System*

The Earthworm possesses a complicated set of organs for sexual reproduction, and since each worm possesses both male and female organs, it is an hermaphroditic animal just as is Hydra. The reproductive organs in the Earthworm, however, are much more highly developed than are those of the Hydra. In the first place, they are permanent organs, and, in the second place, the reproductive system of the Earthworm is greatly complicated by the presence of an elaborate arrangement of accessory structures so that sperm from two animals may be exchanged in order to bring about cross-fertilization, that is, the fertilization of the eggs of one animal by the sperm of another. (W. f. 60.)

MALE ORGANS OF REPRODUCTION. These consist of (a) two pairs of TESTES situated close to the ventral body wall and attached to the anterior septum of segments x and xi. The testes constitute the essential part of the male organs of reproduction, for it is in them that the sperm are formed. Each pair is enclosed by a special fluid-filled cavity in the coelom, the TESTIS SAC, developed ventrally in segments x and xi.

(b) A pair of sac-like SEMINAL VESICLES is found in segments ix, xi, and xii, making three pairs in all. The seminal vesicles are directly connected with the testis sacs; those in ix and xi with the sac in x, and the pair in xii with the sac in xi. The sperm are formed primarily in the testes, but before they are mature they are released into the enclosing testis sacs and thence into the seminal vesicles. Here they remain for a time and undergo final development. Finally, they are again passed into the testis sacs, and then into the openings of the sperm ducts for passage to the exterior.

(c) A pair of SPERM DUCTS open externally, one to the right

and one to the left, on the ventral surface of segment 15. From the external opening each of these sperm ducts continues forward internally to segment xii, where it divides, one branch of each running to the testis sacs in x and xi. In these sacs the sperm ducts end in ciliated, funnel-shaped openings adapted for drawing the sperm into the ducts, from which the latter pass to the exterior, as noted above.

FEMALE ORGANS OF REPRODUCTION. These consist of a single pair of **OVARIES** situated ventrally in xiii. The eggs which develop in them are set free directly into the cavity of the coelom in segment xiii and pass into the **OVIDUCTS** which open internally in this segment. The external opening of each oviduct is through the ventral body wall of segment xiv. Each oviduct begins in xiii as a ciliated, funnel-shaped opening situated near the ovary of that side. The eggs may remain for a time in an enlarged anterior portion of the oviduct, the **OVISAC**, before leaving the body.

The **CLITELLUM**, which has been mentioned earlier, is a differentiated glandular structure present in the body wall, normally situated between segments xxxii and xxxvii. It serves as an accessory organ during reproduction by the secretion of material which forms a case in which the embryos develop, as described below.

In addition, the Earthworm possesses two pairs of **SEMINAL RECEPTACLES** attached laterally and close to the posterior septum of segments ix and x. These open directly to the exterior through the ventral body wall in the grooves between segments ix/x, and x/xi. The seminal receptacles remain empty most of the year, but at the breeding season when the worms pair, they are filled with sperm received from another worm, and it is this foreign sperm that is used to fertilize the eggs.

FUNCTIONAL. The breeding season begins early in the spring. At this time the seminal vesicles of each worm are well-filled with mature sperm which have been developing since the previous breeding period. In order to bring about an exchange of sperm, two worms come into contact, with the head ends pointed in opposite directions, in such a way as to bring the openings of the seminal receptacles of one worm on segments ix/x in close apposition to the ventral surface of the clitellum of the other worm. The mucus glands in the skin between segments ix and xxxvii now become active and secrete a mucus envelope, or **SLIME TUBE**, covering the

anterior end of each worm. This hardens somewhat and with the aid of additional material secreted by certain specialized ventral glands holds the two animals securely together.

Sperm is now discharged by each worm from the openings of the sperm ducts on segment xv. It is forced posteriorly, under the slime tube and in a fine groove in the body wall, to the clitellar region. Here the sperm is passed into the openings of the seminal receptacles of the other worm which, it will be remembered, are being held in close apposition. After the exchange of sperm the worms break loose from their coverings and separate.

In each animal certain glandular cells of the clitellum now become active and secrete mucus material to form a resistant, hollow, elastic ring entirely around the body, which is filled with a jelly-like nutrient substance also secreted by clitellar cells. This band is then gradually worked forward by contractions of the body wall. It receives a few egg cells as they are passed from the oviduct openings at xiv, and sperm, previously received from another individual, at the openings of the seminal receptacles at ix/x/xi. The band, now containing eggs and sperm, is moved further anteriorly, and, finally, after passing entirely from the animal, contracts to form a small rounded EGG CASE, in which the eggs, fertilized by the foreign sperm, develop.

After fertilization the eggs begin to divide. The cleavage of the egg of an Earthworm is somewhat unequal and irregular, but there are soon formed, just as in the development of *Hydra*, a hollow sphere, the BLASTULA, and then a two-layered GASTRULA, the wall of which is composed of an outer ECTODERM layer and an inner ENDODERM layer. Soon MESODERM is formed between the ectoderm and endoderm, and it is within the mesoderm, as previously described (p. 66), that the coelom arises, which is so important a structural feature of the Earthworm and the higher forms of animals. (W. f. 173.)

ASEXUAL REPRODUCTION BY REGENERATION. In the Earthworm, the normal method of reproduction is sexual, as has just been described. This animal, however, shows great powers of regeneration which under certain conditions may amount to asexual reproduction. For example, if an Earthworm is cut transversely through the middle of the body, each half will regenerate almost completely. Other species of Annelida are known in which the power of regeneration is even greater than in the Earthworm.

In such forms a very small portion will regenerate a complete worm. (W. f. 160).

6. *Nervous System*

The Earthworm possesses a much higher type of nervous system than that of Hydra. It consists, as in the higher animals, of the CENTRAL NERVOUS SYSTEM and the PERIPHERAL NERVOUS SYSTEM. The former consists of a VENTRAL NERVE CORD, which lies in the coelom, ventral to the alimentary canal, in a median line. It begins at the extreme anterior end of the animal and continues throughout its entire length, enlarging in each segment to form a GANGLION.¹ In segment iv, just under the anterior end of the pharynx, the cord divides to form a NERVE COLLAR, composed of the CIRCUMPHARYNGEAL CONNECTIVES, which completely encircles the pharynx. On the dorsal side of the nerve collar, lying above the pharynx in segment iii, is a bilobed swelling which constitutes the CEREBRAL GANGLION. This may be regarded as the BRAIN of the animal. Running forward from the cerebral ganglion are two pairs of nerves, from which a number of tiny branches arise to innervate the prostomial region. (W. fs. 59, C; 66.)

The peripheral nervous system consists of paired nerve trunks which are given off from the nerve cord in each segment and which innervate the various parts of the body. There is a definite arrangement of these peripheral nerves in each segment which we may now indicate. (a) Just back of the anterior septum in each segment a pair of nerves is given off: one of the pair penetrates the body wall on the right side of the body, and the other occupies a corresponding position on the left side of the body. (b) From each of the segmental ganglia of the ventral nerve cord two pairs of nerves arise, two of which run to the right side of the body and two to the left. (c) The extreme anterior segmental ganglion, located in segment iv just posterior to the division to form the nerve collar, is known as the SUBESOPHAGEAL GANGLION, and from this ganglion several pairs of nerves are given off which aid in innervating the anterior segments. The two pairs of nerves running anteriorly from the cerebral ganglion also belong to the peripheral nervous system.

Each of the peripheral nerves, except those arising in segments iii and iv, run laterally for a short distance, then divide into a dorsal

¹ Plural, ganglia.

and ventral branch for the innervation of the body wall. Each of the posterior nerves in a segment gives off a septal nerve which runs dorsally along the septum to innervate the alimentary canal.

The structural features of the nerve tissue as revealed by microscopic study may now be described. Considering first the ventral nerve cord in the region of a ganglion, we find on the outside a sheath of non-nervous tissue, which consists, externally, of a layer of epithelial cells similar to those which cover various other organs in the coelom. Then comes an inner sheath layer consisting largely of connective tissue, but also containing numerous muscle fibers and blood vessels. (W. f. 139.)

Embedded dorsally in the cord, below the inner sheath layer, are three tubular structures, the GIANT FIBERS, which extend practically the entire length of the cord. The median giant fiber is somewhat larger than the other two which lie laterally. All three fibers are connected with each other and with processes from the nerve cells at regular intervals along the cord. It is clear that they have important nervous functions and, therefore, are better designated as neurochords.

In *Lumbricus*, although the nerve cord has the appearance of a single structure, certain features of the internal arrangement are quite markedly bilateral. As a matter of fact, in certain other species, two separate ventral cords are found which are connected segmentally by transverse fibers. The bilobed central region of the cord is largely occupied by innumerable fine nerve fibers which form a dense interlacing mass. The nerve cells, or NEURONS, from which the fibers arise, constitute the basic structural and functional units. They are situated in the ventral and lateral portions of the cord, below the fiber mass. The neurons are much more numerous in the ganglia of the cord than in the interganglionic regions.

A typical neuron may be described as a pear-shaped cell with a prominent nucleus. At one end the cytoplasm is extended to form a long process, the AXON, and, at the other end, one or more DENDRITES which are somewhat smaller. Functionally it is clear that a neuron receives communications by way of the dendrites, and that the response is sent from the neuron to the peripheral regions over the axon.

We may distinguish three types of neurons. There is, first, the

MOTOR NEURON with the cell bodies present in the ventral nerve cord, and the axons extending peripherally for considerable distances to innervate the muscle tissue in the body wall and alimentary canal. A second type is the SENSORY NEURON with the cell bodies situated in the various tissues and organs all over the body, but particularly in the epithelial layer where they are in close contact with the environment. The axons from the sensory neurons run to the ventral nerve cord. A third important type, the ADJUSTOR NEURON, is situated entirely within the nerve cord where contact (SYNAPSE) is made with the axons from the sensory cells and with the dendrites of the motor cells. The segmental, peripheral nerve trunks consist of many axons insulated from each other and bound together with supporting tissues to form the definitive nerve. Each nerve contains both motor and sensory axons. (W. f. 138.)

It is this differentiation of the neurons that makes it possible to bring about harmonious action in response to a stimulus. For example, if the skin of a living Earthworm is touched with a dissecting needle, coördinated movements of the body will follow almost immediately. In such a case the sensory neurons in the peripheral regions receive the external stimulus, and a nerve impulse is transmitted from them over their sensory axons to the central nervous system. Here in the cord the message is transferred to the adjustor neurons which, in turn, refer it to the proper motor neurons whose axons innervate the muscle fibers in the affected region. The muscles then contract in accordance with the stimulus originally received by the sensory cells. Such a circuit is known as a REFLEX ARC, and the resulting action as a REFLEX ACTION.

SENSE ORGANS. The sensory neurons in various regions of the body may be specialized for the reception of a particular type or types of environmental stimuli, and also grouped together to form definite SENSE ORGANS of essentially the same nature as in the higher Vertebrate animals. Although the sense organs of the Earthworm are microscopic in size they nevertheless exhibit remarkable differentiation. Thus for receiving stimuli from light waves there are modified sensory neurons, or PHOTORECEPTOR CELLS, present in the skin epidermis and grouped at intervals along certain nerves. They are particularly abundant in the prostomial region and at the extreme posterior end of the body.

The photoreceptor cells are characterized structurally by a network of nerve fibrils in the cytoplasm and by the presence of a peculiar transparent lens-like structure which serves to focus the light rays on the nerve fibrils in certain regions of the cell. The sensory organs of the head region are much more highly developed in the marine worms, such as *Nereis* (p. 83), than they are in the Earthworms.

For the reception of tactile, chemical, and thermal stimuli, there are single sensory cells and also numerous and widely distributed EPIDERMAL SENSE ORGANS. Each one of these structures consists of several sensory neurons which are very different from those of the 'eye' just noted. They may be described as elongated cells having a number of very tiny sense hairs at one end and a nerve fiber at the other. They are so arranged that the sense hairs may be projected to the exterior through definite openings, and thus put in a favorable situation to receive the stimuli.

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XII. CRAYFISH

THE Crayfish is a common example of a very large and important phylum of segmented Invertebrates, known as the Arthropoda and characterized, as the name indicates, by the presence of jointed appendages. Typically there is a pair of such appendages on every segment, but as will be seen from our studies of various representatives of this phylum, wide variations may be found in the number of pairs present as well as in the structural and functional features. All these types of appendages are believed to be related to a basic ancestral type and are, therefore, said to be HOMOLOGOUS.

The Arthropoda are triploblastic, bilaterally symmetrical animals with a ventral nerve cord, and it may be said, in general, that various structural features are present which seem to link them rather closely with the Annelida. In fact, one primitive Arthropod genus, *Peripatus*, is very definitely worm-like in its general structural plan but, nevertheless, has jointed appendages and other Arthropod structures. On the whole, though, it is very evident that the organization of the Arthropoda is more advanced than that of the Annelida. Thus the number of segments is definite and limited in Arthropod species, and typically exhibit a considerable degree of segmental specialization and fusion to form three body regions, the head, thorax, and abdomen. The development of the anterior end of the body to form a definite head — the process of CEPHALIZATION — together with a marked concentration of the nervous system and the formation of extremely sensitive and highly differentiated regions of it for the reception of external stimuli are all features of great interest and importance.

A. EXTERNAL STRUCTURE

The Crayfish has an elongated body, generally about six inches in length when fully extended. The entire body is covered by a rigid covering (EXOSKELETON) which is formed as a secretion by the underlying epithelial cells. In the anterior portion of the body (CEPHALOTHORAX) the dorsal exoskeleton is unsegmented, and is termed the CARAPACE. It ends in an anterior projection

(ROSTRUM). In the posterior portion of the body (ABDOMEN) the segmentation is clearly marked. The exoskeleton covering each abdominal segment consists of a curved dorsal portion (TERGUM) connected by a ventral, transverse bar (STERNUM). The ends of the tergum (PLEURA) project ventrally below the sternum. (W. f. 65.)

Altogether there are twenty-one segments in the body of the Crayfish, of which segments i-vi constitute the head, segments vii-xiv constitute the thorax, and segments xv-xxi the abdomen. Attached to every segment except the first and last is a pair of JOINTED APPENDAGES. The first segment bears the eyes, but these are not usually regarded as being homologous with the appendages. Also the last segment of the body, the TELSON, does not possess appendages, thus leaving a total of nineteen pairs of appendages. (W. f. 63.)

B. STRUCTURE OF THE APPENDAGES

The appendages of the Crayfish may be divided into two general types as follows (W. fs. 63, 64):

(1) The BIRAMOUS APPENDAGE is found in a typical form on most of the abdominal segments and in a highly modified form on the head segments. A typical biramous abdominal appendage consists of a basal portion, the PROPODITE, which is composed of two segments: the COXOPODITE, attached to the body, and the BASIPODITE. The latter bears two jointed branches: the inner termed the ENDOPODITE, and the outer the EXOPODITE. This form of appendage is believed to represent the primitive and fundamental type from which the modified types of appendages have been derived.

(2) The UNIRAMOUS APPENDAGE is represented by the walking legs. In this modified type of appendage the propodite shows the same general structure as in the biramous appendage, but the exopodite is always lacking, so that the basipodite bears only one branch, the endopodite. Attached to the coxopodite of certain of the walking legs is a gill-bearing structure, the EPIPODITE, which aids in respiration as indicated later.

In giving a description of the appendages of the Crayfish, we shall begin with those present on the abdomen inasmuch as they are more simple and are believed to represent, as noted above, the fundamental type.



FIGURE 7

The Japanese Spider Crab (*Macrocheira*). From specimen at Peabody Museum, Yale University. Description on page 112.
(After *Doflein*.)

1. *Abdominal Appendages*

The last pair of appendages on the abdomen, the **UROPODS**, is attached to segment **xx**. They are biramous and both the endopodite and exopodite are essentially broad, flat plates adapted for use in swimming.

Each of the next four abdominal segments (**xvi-xix**) on the female bears a pair of typical, small biramous appendages. The exopodite of each of these abdominal swimmerets consists of a flattened, blade-like structure made up of several joints. The endopodite is similar in structure, but is somewhat larger. The abdominal appendage on segment **xv** of the female is greatly reduced and not functional. On the male the abdominal appendages of segments **xv** and **xvi** are very atypical, being modified for the transference of sperm. (W. f. 65.)

2. *Thoracic Appendages*

There are five pairs of uniramous walking legs attached to segments **x-xiv**, all of which are built on the same plan. The protopodite is made up of the coxopodite and the basipodite. The coxopodite bears the epipodite, with the attached gill filaments which project dorsally into the gill chamber. The epipodite is present on all the walking legs except the last pair on segment **xiv**. The basipodite bears a five-jointed endopodite, the last two joints of which may form a pincer, or chela. The pincers on the first pair of walking legs are large and serve as formidable weapons. Smaller pincers are present on the next two pairs of walking legs, but are lacking on the last two pairs. The exopodite is never present.

A pair of mouth parts is present on each of the segments **vii**, **viii**, and **ix**. These appendages are known respectively as the **FIRST**, **SECOND**, and **THIRD MAXILLIPEDS**. Each of these has a basal protopodite, composed of the coxopodite and basipodite, and also a gill-bearing epipodite, noted above. The epipodite of the first maxilliped, however, lacks the gill filaments. The third maxilliped on segment **ix** is the largest. In this appendage, the exopodite is comparatively short, and consists of a basal portion bearing a flexible, filamentous structure. The endopodite is much larger than the exopodite and is composed of five joints, the general structure being somewhat like the endopodite of the walking legs, except that a pincer is not present. The first and second maxillipeds are smaller than the third maxilliped, but their structure is

much the same. The maxillipeds are more or less covered with hairs, some of which are believed to serve as chemical sense organs and others as tactile sense organs. The maxillipeds aid in holding the food. (W. f. 64.)

3. *Head Appendages*

Segments v and vi each bears a pair of appendages, known as the FIRST and SECOND MAXILLAE. The second maxilla, on segment vi, is one of the most highly modified appendages of the entire body. The protopodite is quite unusual and consists of thin, pliable plates. The exopodite has become greatly modified and, together with the epipodite, forms a broad, flat structure, the SCAPHOGNATHITE, which, by its movements in the gill chamber, keeps a current of water passing over the gills. The endopodite is a small filament consisting of only one segment. The first maxilla, on segment v, is one of the smallest appendages and consists of the protopodite and the endopodite which is a small, atypical structure. The exopodite is entirely lacking. Segment iv bears a pair of jaws, or MANDIBLES. Each mandible consists chiefly of a protopodite which is made up of two segments, and to which very heavy muscles are attached. The exopodite is lacking and the endopodite is greatly reduced. The mandibles are primarily used for crushing the food. (W. f. 64.)

Segments ii and iii bear a pair of ANTENNULES and ANTENNAE respectively. The antennae are considerably larger than the antennules. The protopodite of each antenna is made up of two segments. The proximal segments bear an opening of an excretory organ known as the GREEN GLAND. The exopodite of the antennae is a short, thin, blade-like structure, which projects laterally, while the endopodite is a long, many-jointed, whip-like structure. The antennules have a protopodite which is made up of three segments, the proximal one of which contains a sensory organ, known as the STATOCYST. The exopodite and the endopodite are practically of the same length and, although somewhat smaller, have the same structure as the endopodites of the antennae. The antennules and antennae are primarily sense organs.

AUTOTOMY AND REGENERATION OF THE APPENDAGES. Many of the Crustacea, including the Crayfish, possess the power of casting off an injured appendage. This is known as AUTOTOMY. There is a definite breaking joint between the second and third segments of the walking legs, and when these appendages are injured, the

distal end is definitely broken off. Then a process of regeneration begins which soon restores the appendage to the original condition. Autotomy is under the control of the nervous system and is brought about by a series of muscular contractions. In addition to regeneration as a result of autotomy, the Crayfish, particularly when young, possesses regenerative power sufficient to form entire appendages when the original ones are removed. The regenerated appendage, however, does not always have exactly the same structure as the one which was lost.

C. ORGAN SYSTEMS

1. *Nutritive System*

The alimentary canal of the Crayfish begins with the mouth which opens between the mandibles on the ventral surface of the third segment. Leading dorsally from the mouth is a short, undifferentiated tube, the esophagus, which opens into the stomach almost directly above the mouth. The stomach is a highly specialized organ and is divided into two parts: an anterior portion (CARDIAC CHAMBER), into the ventral surface of which the esophagus opens, and a somewhat smaller posterior portion (PYLORIC CHAMBER). In the lining of the stomach are a number of peculiar chitinous OSSICLES which together constitute a complicated food-grinding apparatus, the GASTRIC MILL. The muscle layers in the wall of the stomach are able to contract in such a way as to cause the ossicles to work against each other and thus to grind, or masticate, the food. Between the cardiac and pyloric portions is a strainer consisting of numerous bristle-like structures. The food must be finely ground in order to get through the strainer in passing from the cardiac into the pyloric portion of the stomach.

Leading from the posterior end of the pyloric chamber is the tube-like INTESTINE, which continues almost directly posteriorly through the center of the abdomen. It opens ventrally through the ANUS in the last segment of the body. Large DIGESTIVE GLANDS, which correspond to those present in higher forms, are located in the cephalothorax, and these produce a secretion which contains certain digestive enzymes. The secretion passes into the pyloric chamber of the stomach through the hepatic ducts. The food of the Crayfish consists both of living and dead animal matter. The process of digestion does not differ fundamentally from that

already considered in the Earthworm. A further discussion of the process may be left until the Vertebrate is considered. (W. f. 63.)

2. *Vascular System*

The vascular system consists of a number of muscular-walled vessels, the ARTERIES; a pumping organ, the HEART; a series of blood spaces, the SINUSES, distributed through various regions of the body; and, finally, a circulating medium, the BLOOD, which is essentially similar to that of the Earthworm.

The single heart of the Crayfish is a contractile, muscular organ which develops as a dilation of a dorsal blood vessel. The latter occupies a similar position to that found in the Earthworm. The heart lies in the cephalothorax, in a median plane, quite close to the dorsal integument. When the exoskeleton is removed from this region it will be seen that the heart lies in a chamber, the PERICARDIAL SINUS. Viewed from above the heart shows a somewhat irregular, pentagonal shape. It is kept in position by six strands of fibrous tissue which originate from the walls of the heart and extend to each side, where they are attached to the wall (PERICARDIUM) of the pericardial sinus.

Leading from the heart are the six main arteries, including two pairs, which convey the blood from the heart to various parts of the body. These may now be described. (W. f. 63.)

Anterior Median Artery. This is an unpaired artery that leaves the heart at the extreme anterior end and continues anteriorly, giving off branches which supply the cardiac portion of the stomach, the esophagus, and portions of the head region.

Antennary Arteries. A pair of these arises at the anterior end of the heart, one on each side of the median artery. They run anteriorly for a short distance and then ventrally and laterally, one to the right and one to the left. Each of these arteries gives off a branch which runs to the cardiac portion of the stomach, and other branches which supply various organs in the head region, notably the muscles and the antennae with the green glands.

Hepatic Arteries. A pair of these arises from the anterior end of the heart, just posterior and ventral to the antennary arteries. As indicated by the name, they supply the digestive glands.

Dorsal Abdominal Artery and Branches. This large vessel leaves the ventral side of the heart at the extreme posterior end. It runs directly posteriorly through the abdomen, close to the

dorsal body wall, and gives off branches which supply the muscle tissue of this region. A large branch, the STERNAL ARTERY, arises from the abdominal artery just after it leaves the heart. The sternal artery continues ventrally, at right angles to the abdominal artery, till it reaches the ventral body wall. The ventral nerve cord of the Crayfish at this point splits into two cords which are united at the segmental ganglia. The sternal artery passes between the two nerve cords and, underneath them, divides into (a) the VENTRAL THORACIC ARTERY, which runs anteriorly under the nerve cord, and (b) the VENTRAL ABDOMINAL ARTERY, which runs posteriorly and occupies a corresponding position.

There are six openings (OSTIA ¹) in the muscular walls of the heart through which blood passes into the heart from the surrounding pericardial sinus. One pair of these ostia opens through the dorsal wall, one pair through the ventral wall, and one pair opens through the sides. All of the ostia are provided with simple valves which prevent the outflow of blood.

Having considered the heart and the vessels leading from it, we are now in a position to note the position of the large blood spaces, or sinuses, which are present in various regions of the body and in which the blood is collected and finally returned to the heart. The PERICARDIAL SINUS, which surrounds the heart, has already been noted. The main sinus of the body is known as the STERNAL SINUS. It is situated on the ventral side of the body in the region of the thorax. Leading from the sternal sinus are a number of channels which run into the organs for aërating the blood, the GILLS. After passing through the gills the blood flows dorsally into the pericardial sinus. The alimentary canal in the cephalothorax is surrounded by the PERIVISCERAL SINUS.

The general course of the circulation of the blood is as follows: The blood, which passes from the surrounding pericardial sinus through the paired ostia and into the heart, is forced out by the rhythmical contractions of the muscular walls into the various arteries mentioned above. Thus the heart drives the blood both anteriorly (median, antennary, hepatic, and ventral thoracic arteries) and posteriorly (dorsal and ventral abdominal arteries) to supply all regions of the body. In the tissues the blood is gradually collected in the sinuses, all of which finally open into the large sternal sinus. The blood which flows to the sternal sinus from

¹ Singular, ostium.

the perivisceral sinus surrounding the alimentary canal carries absorbed food materials as well as metabolic wastes.

The next step is the passage of the blood from the sternal sinus through the vessels in the GILLS. These important respiratory organs of the Crayfish are attached, as noted below, either by means of the epipodites to certain appendages or to membranes which are present near the base of the appendages. After passing through the gills, the oxygenated blood flows dorsally through a number of canals (BRANCHIO-CARDIAC CANALS) which lead into the pericardial sinus, from which it is drawn into the heart through the ostia, and thus the cycle is completed.

3. Respiratory System

In the Earthworm it was noted that the entire surface of the body acted as a medium through which the blood, plentifully supplied to the body wall, could exchange its waste carbon dioxide for the essential oxygen. In the Crayfish this phase of respiration is performed by a much more elaborate mechanism consisting of the branched, filamentous gills present in the gill chamber of the thorax. The gill chamber, on either side of the thorax, lies outside of the body wall. It is the space between the outer, chitinous exoskeleton and the true body wall of the thorax, dorsal to the attachment of the appendages. A current of water is forced through each gill chamber by the paddle-shaped scaphognathite which, as previously noted, is a part of the second maxilla at the anterior end of the gill chamber. (W. pp. 161-162.)

The gills in the common American species, *Cambarus affinis*, are attached either to the coxopodites of the appendages (PODOBRANCHIAE) or to membranes developed at the bases of the appendages (ARTHROBRANCHIAE). In the European genus *Astacus* another row of gills (PLEUROBRANCHIAE) is present which are attached to the walls of the thorax. The number of gills varies in different species, but in *Cambarus* there are 17 gills in the gill chamber on each side of the thorax: six are podobranchiae, and eleven are arthrobranchiae.

Each gill may be described as a plume-like structure with a central stem, or epipodite, to which a large number of fine filaments, the BRANCHIAE, are attached. Running through the stem and branching into the filaments are two blood vessels, an EFFERENT BRANCHIAL VESSEL which carries blood into the gills from the

sternal sinus, and an **AFFERENT BRANCHIAL VESSEL** which carries blood from the gills. In the gill filaments these vessels are connected by many tiny capillaries, and as the blood passes through them, the gaseous interchange takes place. The gill filaments are very thin-walled and are continually bathed in the water which passes through the gill chamber. The blood, with a new supply of oxygen for the tissues, passes from the gills through the afferent branchial vessels, and finally reaches the pericardial sinus from which it passes into the heart and is pumped to all parts of the body.

4. *Excretory System*

The excretory organs of the Crayfish are unusual in their structure and not obviously similar to the nephridia of the Earthworm, although it is generally held that they are homologous with the latter. They consist of a pair of small bodies, the **GREEN GLANDS**, which are situated in the posterior part of the head, at the base of each antenna. Each green gland consists of three parts: (a) a **GLANDULAR PORTION**, which takes the wastes from the blood; (b) a thin-walled, sac-like **BLADDER**, which receives the wastes given off by the glandular portion; and, leading from the bladder, (c) a fine tube which opens to the exterior through the wall of the basal segment of each of the antenna. The green glands are vascularized by small branches from the antennary arteries. The blood, which they receive, passes through the glandular portion of the organ, and the nitrogenous wastes are taken from it. (W. f. 63.)

5. *Reproductive System*

The Crayfish is a **DIOECIOUS** animal; that is, the two sexes are separate. This is different from the hermaphroditic condition which has previously been noted in the Earthworm.

MALE ORGANS OF REPRODUCTION. The sperm are developed in one testis situated near the pericardium. The anterior portion of the testis is bilobed, while the posterior end is single. Leading from the right side of the posterior portion is a duct, the **VAS DEFERENS**, which opens to the exterior through the coxopodite of the fifth walking leg. The vas deferens from the left side of the testis has the same structure. The testis is largely composed of a mass of fine tubules in the walls of which the sperm are formed. When the sperm have reached the proper stage of maturity, they pass

down the tubules and eventually leave the testis through the right or left vas deferens.

FEMALE ORGANS OF REPRODUCTION. The eggs are developed in a bilobed ovary which is situated in the same general region in the female as is the testis in the male. Leading from the ovary are two tubes (OVIDUCTS), each of which opens to the exterior through the coxopodite of the third walking leg. The ovary of the Crayfish contains a central cavity connected with the oviducts. The eggs are formed from the definitive germ cells located in the wall of the ovary. When ripe they break loose from the wall into the central cavity from which they are taken to the exterior by the oviducts.

DEVELOPMENT OF THE CRAYFISH. The breeding season of the Crayfish is in the fall. At this time the two sexes pair, and sperm cells are transferred from the male to the female by means of the specialized abdominal appendages. The sperm cells remain during the winter in a small cavity, the SEMINAL RECEPTACLE, situated on the ventral surface of the body of the female, between the fourth and fifth walking legs. The following spring, the mature eggs developed in the ovary are laid, after being fertilized by the sperm from the male which were previously stored in the seminal receptacle. The fertilized eggs are attached by a sticky secretion to bristles present on the abdominal appendages, with the result that almost the entire ventral surface of the abdomen of the female may be covered with the developing eggs, each enclosed in a special protective capsule.

When the egg has been fertilized, cell division begins. However, the entire fertilized egg, or zygote, of the Crayfish does not divide at first, but only the fertilization nucleus, or synkaryon. The latter divides to form a number of nuclei which lie in the center of the developing zygote. These nuclei later migrate to the surface of the zygote, and then the cytoplasm divides radially into as many parts as there are nuclei. Division at right angles then occurs in such a manner as to cut off a small peripheral portion of the cytoplasm, surrounding each nucleus, from each of the radial parts. Thus, at this stage, the embryo consists of an outer, or surface, layer of cells which contain the nuclei and enclose an inner mass of yolk material. The latter does not play any direct part in the further development of the embryo, but supplies the necessary nourishment.

When the young embryo has reached a certain stage of development it hatches; that is to say, it breaks out of the egg capsule which has thus far enclosed it and becomes more or less independent. It is, however, still attached to an abdominal appendage of the mother by means of a filament which runs to the embryonic telson. Three successive growth stages, or MOLTS, occur, during each of which the exoskeleton is shed. The animal finally detaches itself from the mother, and thus becomes a free-living Crayfish of small size, but in general appearance like the adult.

6. *Nervous System*

The nervous system of the Crayfish has the same general structural plan as that which has already been noted in the Earthworm. There is a main VENTRAL NERVE CORD with GANGLIA running the entire length of the body. This constitutes the CENTRAL NERVOUS SYSTEM, and from it, at the ganglia, peripheral branches are given off which run to all parts of the body. There are, however, certain points of difference between the nervous system of the Crayfish and that of the Earthworm. These may be summarized as follows (W. f. 92):

(a) In the Crayfish the arrangement of the ganglia in the ventral nerve cord does not correspond to the external segmentation throughout the entire length of the body. This is particularly true in the cephalothorax. Altogether there are 13 ganglia present on the ventral nerve cord, and since there are 21 segments in the body it is apparent that either several ganglia are lacking or else there has been a consolidation of certain ones. The facts indicate that a fusion has occurred in certain ganglia of the head and thorax.

(b) In the Crayfish there are a considerable number of SENSE ORGANS present which are adapted for receiving various kinds of external stimuli such as tactile, olfactory, auditory, and photic. In every type of sense organ, the sensory neurons receive the stimuli and transmit them to the central nervous system.

The CEREBRAL GANGLION, lying just back of the eyes, is regarded as the most important ganglion in the body, and constitutes the brain of the animal, just as in the Earthworm. A number of peripheral nerves are given off from this ganglion, which run anteriorly and laterally, and innervate the antennules, antennae, and

eyes. The SUBESOPHAGEAL GANGLION gives off a number of nerves which supply the mandibles, maxillae, and the first two pairs of maxillipeds. The remainder of the ganglia present in the ventral nerve cord give off branches which, in general, supply the appendages, muscles, and other organs lying near the region in which they are situated. For the most part the branches arising in all these ganglia, except the cerebral ganglion, are motor in function. (W. f. 63.)

SENSE ORGANS. The surface of the body is entirely covered with the hard, chitinous exoskeleton and is not provided with scattered sensory nerve cells as is the case in the skin of the Earthworm. Thus the sensory tissue in the Crayfish is largely grouped in the special sense organs situated in the anterior end of the body. These may now be noted.

(a) *Tactile Organs.* Scattered over the appendages as well as in some other regions of the body are found many fine filaments, or setae, which are believed to be tactile sense organs. Each of these setae is directly connected with a tiny nerve fiber, and anything which comes into contact with the setae sets up an impulse along the attached nerve.

(b) *Olfactory Organs.* It is believed that certain jointed filaments, which are present in small groups on the under surface of the exopodites of the antennules have an olfactory function.

(c) *Organs of Hearing or Position.* Situated in the basal joint of each antennule is a sac, the STATOCYST, which contains a great number of very fine hairs distributed along two ridges. A nerve runs into the base of the sac, and branches from it are distributed to the neurons. Among these hairs, grains of sand (STATOLITHS) are commonly found, and these may be attached to the hairs. Although this structure was originally thought to be a sound-receiving organ, experimental work has apparently shown that its real function is that of equilibration. In other words, it gives the animal a sense of position. It has been found, for example, that animals from which the statoliths have been removed are unable to orient themselves and, furthermore, if the sand grains are replaced by fine iron filings, then the equilibrium of an animal can be influenced by the use of a magnet.

(d) *Organs of Sight.* The Crayfish possesses a pair of eyes, each borne on a small stalk attached, just dorsal to the antennae, near the anterior end of the head. The eyes are very highly developed,

and inasmuch as each one is composed of about 2500 visual units, termed **OMMATIDIA**, they are known as **COMPOUND EYES**. Each ommatidium is a complicated, elongated, light-receiving structure which is connected at the base with a branch of a nerve from the cerebral ganglion. When this compound eye is viewed from the front, the surface appears as a mosaic made up of a great number of rectangular facets, each of which is the outer end of an ommatidium. These visual units receive light waves from a restricted area, and so the image which the Crayfish receives is believed to be a composite one, built up from the separate images which have been received by the individual ommatidia.

D. GENERAL FACTS OF IMPORTANCE

The Crayfish belongs to a large and important class of the Arthropoda, termed the Crustacea, included in which are such common species as the Lobster, Crab, Shrimp, and Spider Crab. In this connection it is interesting to note that the largest known Crustacean is the Japanese Spider Crab, shown on page 101. Specimens have been found which measured twenty feet across from tip to tip of the outstretched claws of the first pair of legs. They are found at great depths off the coast of Japan. An interesting photograph is shown in the *National Geographic Magazine*, page 72, vol. 54, 1928. On the other hand, many species of small Crustacea, frequently microscopic in size, abound in extraordinary numbers in the fresh and salt waters almost everywhere. Such forms constitute an extremely important source of food for the larger animal types, including the Fishes.

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XIII. INSECTS

THE Insects comprise one of the chief classes of the Arthropoda, and from many standpoints are to be regarded as one of the most remarkable groups in the entire animal kingdom. Numerically, about four-fifths of all the known animal species belong to the Class Insecta. Structurally they are at once one of the most highly specialized groups and one of the most adaptive to nearly every niche in nature. Economically they affect almost every phase of Man's existence, for they include some of his important allies, as well as many of his most destructive enemies which pillage his possessions and ravage by disease. Thus, Insects are of fundamental importance from many standpoints.

The structure of the Insect body presents a number of well-defined characteristics. The body of the adult is clearly divided into head, thorax, and abdomen. Three pairs of legs are present on the thorax and, generally, two pairs of wings. Insects are the only Invertebrates which possess wings. Typically the head consists of six segments, the thorax of three segments, and the abdomen of ten or eleven segments. The segmentation of head and abdomen is subject to some variation. Insects as a group possess a noteworthy and characteristic respiratory system, adapted for air breathing, which consists of a network of fine tubes ramifying throughout the body tissues, designed to carry oxygen directly to the cells without the aid of the blood stream.

The extraordinary number and variety of Insect species make it impossible to gain an adequate conception of the various types in a general course. We shall briefly consider only two types, namely, the Grasshopper and Honeybee, which, on the whole, have been found most satisfactory for an introduction to this field. The Grasshopper may be regarded as a fairly typical Insect in its general structural and functional features. The Bee, on the contrary, is a very highly specialized Insect and may be said to represent the acme of Insect development. It presents a number of extraordinary structural adaptations, a highly organized communal life, and, at the same time, a considerable importance from the economic standpoint.

I. THE GRASSHOPPER

A. EXTERNAL STRUCTURE

The body of the Grasshopper, in common with that of all Arthropods, is enclosed in a resistant chitinous exoskeletal covering, the CUTICULA, which is formed as a secretion of the underlying epithelial cells. The division of the body into three basic regions, head, thorax, and abdomen, is clearly indicated. The body of the Grasshopper consists of twenty segments, of which six constitute the head, three the thorax, and eleven the abdomen. As previously noted in the Crayfish, the segmentation of the exoskeleton of the head and thorax is not well-marked. We may now consider the external structural features of these three primary body divisions. (W. f. 54.)

1. *Head*

The portion of the exoskeleton enclosing the head is termed the EPICRANIUM. Viewed from the anterior, or facial, aspect the following arrangement of parts may be noted :

(a) A pair of large COMPOUND EYES which protrude from either side of the head. Each of these, as in the Crayfish, is composed of a great number of independent visual units, the OMMATIDIA. Three simple eyes, or OCELLI,¹ are present on the front of the head : one near each compound eye and one in the midline between the attachments of the antennae.

(b) A pair of relatively short, jointed ANTENNAE which are attached to the front of the epicranium near the compound eyes, and project anteriorly and dorsally.

(c) Ventral to the antennae a definite line marks the ventral edge of the epicranium, and below this a portion of the exoskeleton, known as the CLYPEUS, is found. A broad upper lip, or LABRUM, lies ventral to the clypeus.

(d) Removal of the clypeus and labrum reveals : (i) a pair of serrated jaws, or MANDIBLES, for grinding ; (ii) a pair of MAXILLAE, each of which bears a segmented MAXILLARY PALP ; and (iii) a lower lip, or LABIUM, which is divided in the median line and bears a LABIAL PALP on each side. The mouth, with (iv) a tongue-like HYPOPHARYNX, opens back of the mandibles.

The mouth parts of the Insects as a group show a remarkable range of variations in correspondence with the various feeding

¹ Singular, ocellus.

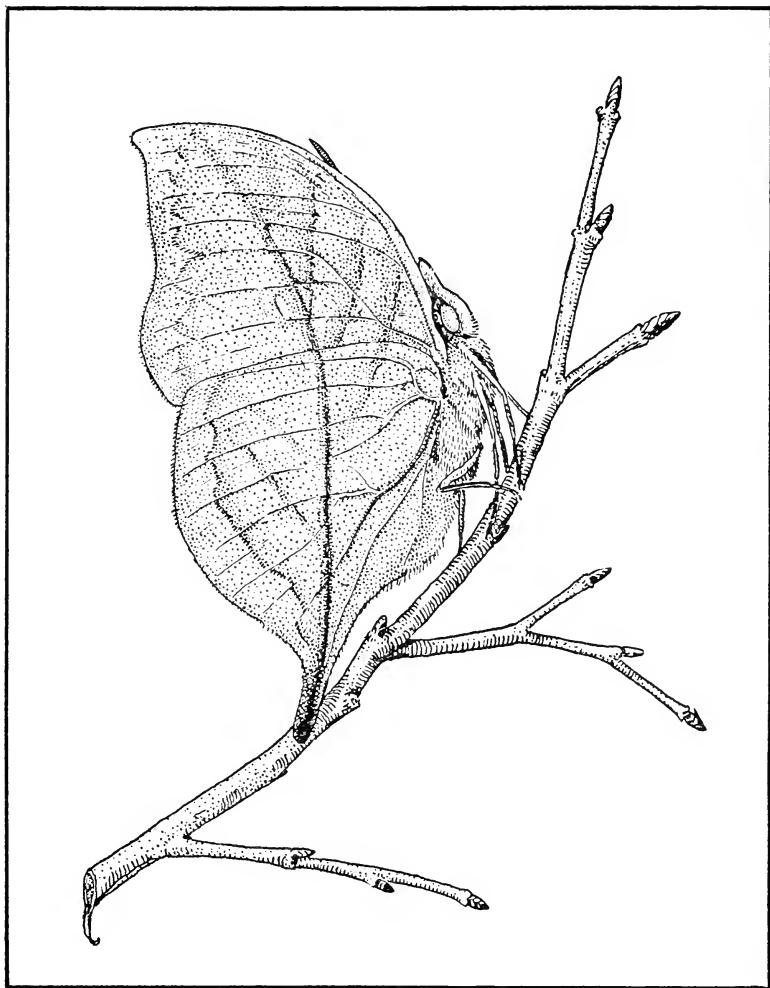


FIGURE 8

Several species of the Leaf-butterfly belonging to the genus *Kallima* are found in India. This Insect may be taken as a good example of the phenomenon known as protective mimicry, numerous examples of which, as well as many other remarkable adaptive features, may be found in the various animal groups. In the case of *Kallima* the general structural features and the coloring of the under surface of the wings, particularly in its usual resting position with the head down, closely resemble a dead leaf which looks as if it were about to be blown away by the first passing breeze.

habits. In other words, the adaptation is very marked. In general, it may be said that there are two main groups of Insect mouth parts, with a great number of sub-varieties of each, and these are designated as the biting type (MANDIBULATE) and sucking type (SUCTORIAL). The mouth parts of the Grasshopper as described above are mandibulate, and are particularly adapted for crushing the plant tissues on which this animal feeds. Those of the Bee, which will be described in the next section, are of the suctorial type and are particularly adapted for sucking the nectar from flowers. However, the mandibles of the Bee are also very well-developed and function in the manipulation of pollen grains and wax. In the Mosquito, suctorial mouth parts, which are designed solely for piercing and sucking, may be seen.

2. *Thorax*

The thorax of the Grasshopper, and of Insects in general, consists of three segments, the anterior of which is termed the PROTHORAX, and then follow the MESOTHORAX and the METATHORAX in the order named. Each of these segments bears a pair of legs, and, in addition, a pair of wings is found on each of the two posterior thoracic segments. (W. f. 54.)

The exoskeleton covering the thorax is divided into a dorsal portion (TERGUM), a lateral portion (PLEURUM), and a ventral portion (STERNUM). The tergum and pleurum are subdivided into a number of SCLERITES.

WINGS. The wings of the anterior, or mesothoracic, pair are large and of a resistant leathery nature. When at rest they lie over and protect the posterior, or metathoracic, pair. The latter are delicate membranous structures which fold fanwise when at rest. They are adapted for flying, and, when extended, a supporting framework of 'veins' can be seen ramifying throughout the wing tissues. The wings are operated by powerful muscles which are enclosed within the thorax.

LEGS. The three pairs of legs are named in accordance with the thoracic segment to which they are attached; that is, the prothoracic, mesothoracic, and metathoracic, legs. The general structure of all is essentially the same, but the metathoracic legs are larger than the other pairs. Each leg consists of five segments. These are: (a) the COXA which forms the attachment with the body; (b) the small TROCHANTER; (c) the large FEMUR which constitutes

the main portion of the leg ; (*d*) the TIBIA, next in size to the femur ; and (*e*) the TARSUS which is composed of five portions, the last, or proximal, of which bears a pair of strong sharp claws, with a pad of tissue, the PULVILLUS, between them.

The legs of the Grasshopper are adapted for maintaining a firm position on the stems and leaves of plants. The comparatively large size of the metathoracic femur makes possible the presence of the large muscles which the animal uses in jumping.

3. *Abdomen*

The abdomen consists of eleven segments. The general external structure of each segment is the same as previously noted in the thoracic segments. At each end of most of the abdominal segments there is an articulation, or connection, with flexible tissue so that a considerable degree of flexion between the segments is possible. Not all of the abdominal segments are complete. Thus the first abdominal segment, which is used with the metathoracic segment, has only the tergum present, and the same is true for the last abdominal segment. In segments ix and x there is an almost complete fusion of the two sterna. (W. f. 54.)

The anterior abdominal segments are larger than the posterior ones, and there is a gradual tapering off in size so that the posterior end of the abdomen, which carries the external genital organs, is fairly pointed. On each of the first eight abdominal segments there is a pair of respiratory openings, or SPIRACLES, situated laterally. Altogether there are ten pairs of spiracles, the other two pairs being situated on the mesothoracic and metathoracic segments.

In the female, the external genital apparatus, which is adapted for laying eggs (OVIPOSITOR), consists of two curved plates, the dorsal and ventral VALVES, projecting from the posterior end of the body. These valves are so fashioned that they can be used for drilling a hole in the soil into which the eggs are placed. In the male Grasshopper, the external genital apparatus consists of several highly specialized chitinous structures which function in the transference of sperm to the seminal receptacle of the female.

B. ORGAN SYSTEMS

The general plan of the internal arrangement of the various organ systems of the Grasshopper is essentially the same as previously described for the Crayfish.

1. *Nutritive System*

The MOUTH lies underneath the mandibles, and from it the small ESOPHAGUS runs dorsally for a short distance, then makes a right angle turn and runs posteriorly into the enlarged CROP which functions as a temporary storage place for food. Branching SALIVARY GLANDS lie beside the esophagus. They extend anteriorly and finally open into the mouth cavity.

Posterior to the crop is a muscular grinding apparatus, the gizzard, or PROVENTRICULUS, and behind that the thinner-walled stomach, or VENTRICULUS. The anterior end of the stomach is surrounded by a number of pouch-like structures, the GASTRIC CAECA, which are responsible for the formation and secretion into the alimentary tract of essential digestive fluids.

Continuing posteriorly from the stomach to the anal opening at the extreme posterior end of the body is the INTESTINE. It appears, for the most part, as an undifferentiated tube except near the posterior end where it enlarges to form the RECTUM, just before opening to the exterior. Mention should also be made of the numerous thread-like MALPIGHIAN TUBULES which form a coiled mass surrounding the intestine for some distance and open into it. These tubules are excretory organs, and they will be described below.

FUNCTIONAL. The food of the Grasshopper, consisting almost entirely of plant tissues, is torn from the plant by the mouth parts and after considerable shredding is passed into the mouth cavity. Here the salivary juice, which contains a starch-digesting enzyme, is added, and then the food material is passed on through the esophagus and into the crop for temporary storage. The gizzard is the next step, and after the food is sufficiently ground, it is in a suitable condition to be digested in the stomach and in the anterior portion of the intestine. Very important in this connection are the enzymes in the digestive fluids secreted into the anterior end of the stomach by the large gastric caeca.

Food materials, after being rendered soluble by the digestive processes, are absorbed by certain of the cells lining the stomach and intestine, while the indigestible materials are passed on through the remainder of the intestine and egested through the anal opening. It is important to note that the alimentary canal is, for the most part, surrounded by a large blood cavity, or HEMOCOEL, and it is

the blood herein contained which receives a considerable portion of the absorbed food materials and later transfers them to the cells as the fluid slowly circulates through the body tissues. Another point of interest in this connection is the large **FAT BODY**, particularly prominent in the larval stages, which lies in the hemocoel surrounding the alimentary canal and which receives excess food for storage.

2. *Respiratory and Vascular System*

RESPIRATION. The Insect respiratory system, which is well-shown in the Grasshopper, is unlike that found in any other phylum of animals. It has as its distinctive functional feature the direct transfer of the respiratory gases to and from the cells. This is accomplished by means of special tubes, the **TRACHEAE**; the external openings, or **SPIRACLES**, of which are seen on the right and left sides of the two posterior thoracic and the eight anterior abdominal segments as previously noted. (W. fs. 54, 116.)

The Grasshopper breathes through the spiracles, and the incoming air, rich in oxygen, is conveyed directly to the cells in all parts of the body by the minute tracheal branches. These are present in such abundance throughout the tissues of the body that all the cells are supplied. The waste carbon dioxide from the cells is eliminated through the same system. Certain abdominal tracheae, in close connection with the spiracles, may be enlarged and united to form two large **AIR SACS** — one lying on either side of the abdomen. The air sacs are particularly well-developed in the more actively flying Insects, such as the Bee.

VASCULAR SYSTEM. Thus in the Grasshopper and other Insects, the tracheal system permits a direct interchange of respiratory gases without the assistance of the vascular system as a transportation agent, as previously observed in the Earthworm and Crayfish. As might be expected under such a condition, the vascular system is not so highly developed in the Insects. This is noted particularly in the general absence of the blood vessels (arteries and veins) which are abundantly present throughout the tissues in animals in which the vascular system serves for the transportation of the respiratory gases to and from the cells.

The tubular vascular system of the Grasshopper consists of a single large contractile **DORSAL BLOOD VESSEL**, or **HEART**, lying close to the dorsal body wall and extending from a blind ending

in the posterior part of the abdomen, through the thorax, to the head region. Throughout most of this vessel there are paired openings, or OSTIA, through which blood enters from the surrounding blood cavity (PERICARDIAL SINUS). The contraction of the dorsal vessel drives the blood to the head region where it leaves the dorsal vessel and flows into the large general hemocoel which occupies so much of the body space in the thorax and abdomen. In the hemocoel, the blood moves posteriorly and ventrally, bathes the various tissues, including the alimentary canal — from which it receives the absorbed food materials for general distribution — and the Malpighian tubules — to which it transfers nitrogenous wastes for excretion. To complete the cycle, the blood, after having been in contact with many of the body tissues, gradually reaches the dorsal pericardial sinus and then passes into the dorsal vessel again through the ostia.

3. *Excretory System*

In our previous discussion of the nutritive system, note was made of the numerous fine, coiled Malpighian tubules lying in the abdomen surrounding the intestine. Each Malpighian tubule opens directly into the intestine at the point of attachment. The other end, which lies free in the hemocoel, is closed. The walls of these tubules are composed of cells which are specialized for absorbing the nitrogenous wastes from the blood in the hemocoel, which continually bathes them. The wastes thus picked up from the blood are secreted into the cavity of the tubule, from which they pass into the intestinal cavity and are excreted with the feces.

4. *Reproductive System*

In all Insects the sexes are separate. Great divergence, however, is to be found with regard to the structural differentiation, or SEXUAL DIMORPHISM, between the two sexes. Thus in some species of Insects the structural differences between male and female are so great that they appear to be from widely separated groups. In others, such as the Grasshopper, the sexual dimorphism is very slight and is marked externally only by structural differences in the external genitals.

MALE REPRODUCTIVE ORGANS. The sperm are produced in a pair of testes which lie above the intestine near the dorsal wall in the third to fifth abdominal segments. The essential elements of

the testes consist of many fine SPERMATIC TUBULES, in the walls of which the sperm develop from the localized germ cells. Connected with each testis and, in fact, with each spermatic tubule, is a larger conducting tubule, the VAS DEFERENS, which runs posteriorly and enlarges to form a SEMINAL VESICLE in which the ripe sperm, passed from the spermatic tubules, may be temporarily stored. Near the posterior end of the abdomen, the right and left seminal vesicles unite in the formation of a common duct which opens to the exterior through the copulatory organ by which the sperm are transferred to the female.

FEMALE REPRODUCTIVE ORGANS. The eggs are produced in a pair of ovaries which are situated in the same relative position in the female as are the testes in the male. Also the general plan of structure of ovary and testis is essentially the same. Thus the ovary consists chiefly of a compact group of OVARIAN TUBULES in which the eggs develop. Leading from each ovary is an OVIDUCT. The right and left oviducts, continuing posteriorly and ventrally from the ovaries, unite in the midline, near the ventral body wall, to form the VAGINA. This opens to the exterior through the highly specialized egg-laying apparatus, the OVIPOSITOR. Opening into the vagina is the SEMINAL RECEPTACLE, in which the male sperm are received, and also a glandular secreting organ, the BURSA COPULATRIX.

FUNCTIONAL. Eggs formed in the ovary pass down the oviducts and into the vagina. Here they are fertilized by sperm previously received from the male and stored in the seminal receptacle. Two membranes are secreted around each fertilized egg, and it is then ready to pass from the female. The female Grasshopper lays the fertilized eggs in a hole in the ground. This she drills very readily by means of the beautifully adapted ovipositor mentioned above. The number of eggs deposited at one time varies, but there may be as many as 35. The fertilized eggs placed in the ground in the fall remain there undergoing development until the following spring when well-formed, but immature Grasshoppers hatch from the eggs and force their way to the surface, where in a short time they become active feeding individuals.

METAMORPHOSIS. Insects, with the exception of a few primitive species, pass through a series of three or four LIFE STAGES during their development. This is known as METAMORPHOSIS. The higher types of Insects, as we shall see later in the Bee, have four

life stages, namely, EGG, LARVA, PUPA, and ADULT. This is known as COMPLETE METAMORPHOSIS, and such Insects are said to be HOLO-METABOLOUS.

In many other groups of Insects, including the Orthoptera to which order the Grasshopper belongs, there are three life stages, namely, EGG, NYMPH, and ADULT. This is known as INCOMPLETE METAMORPHOSIS, and such Insects are said to be HETERO-METABOLOUS.

EGG. The egg of the Grasshopper is heavily yolked so that an adequate supply of food for the developmental stages is provided. The yolk lies in the center of the egg with a layer of cytoplasm surrounding it. It is this outer layer that divides rapidly following fertilization, utilizing the stored food material, and gradually developing to form the highly differentiated Insect. The egg is completely enclosed in two membranes which remain intact until the embryo is ready for independent action, when it breaks through them, or hatches. The inner membrane is known as the VITELLINE MEMBRANE, and constitutes the true cell wall of the egg. The outer one, the CHORION, is a resistant structure secreted by the follicle cells of the ovary which surround the immature egg cells.

NYMPH. The immature Grasshopper, or nymph, which hatches from the egg, is quite close to the adult in most of its structural features, but is considerably smaller; the relative proportions of the various parts are somewhat altered as compared with the adult, the wings are lacking, and the gonads are undeveloped. The nymphs feed and grow rapidly, but, as is the case in all the Arthropods, general increase in size is restricted by the unyielding outer exoskeleton, and so they shed this covering periodically, and form a new one 'a size larger.' Several molts, usually four, occur, and with each one the nymph shows an increase in size and a gradual development to the adult condition. The wings gradually develop from external WING PADS, and at the final molt, which ushers in the adult stage, they are fully formed.

ADULT. This is the stage of sexual maturity, and typically in Insects is a flying stage. No further increase in size occurs although the adult Grasshopper, as well as the nymph, feed voraciously on plant tissues. Mating occurs, and the fertilized eggs are laid in the ground for development as noted above.

5. *Nervous System*

The nervous system of the Grasshopper is closely similar in its general structural features to that in the Crayfish where, it will be remembered, there is a reduced number of ganglia on the ventral nerve cord so that they do not exactly conform to the body segmentation.

The ventral nerve cord of the Grasshopper lies in a median line close to the ventral body wall. The double nature of the cord is clearly evident except at the points where the ganglia are present. Altogether there are ten ganglia present, two of which are in the head, three in the thorax, and five in the abdomen. Of these, the CEREBRAL GANGLION, which constitutes the brain of the animal, is the largest and possibly the most important. The third thoracic ganglion is also very large and of great importance in the innervation of the wings and the last two pairs of legs.

SENSE ORGANS. In general, the sense organs of all the Insects are much the same and accordingly we shall consider them in connection with our study of the Bee, in which they are very highly developed. However, mention at this point should be made of the organs of hearing in the Grasshopper which are particularly well-differentiated. A pair of these organs is present on the first segment of the abdomen, one on each side of the body. Each 'ear' consists of an oval-shaped plate, or TYMPANUM, which is embedded in the body wall at the surface. Underneath the tympanum is a small pit with sensory cells from which a nerve extends to the third thoracic ganglion. Stimuli arising from the vibrations of the tympanum are transmitted over the nerve to the ganglion.

II. HONEY BEE

A. EXTERNAL STRUCTURE

In an active colony, or hive, three types of Bees are found which differ both in their structure and in their functions to the colony as a whole. There are several hundred fertile males, the DRONES, one fertile female, the QUEEN, and several thousand infertile females, the WORKERS. In the fall when the active period of the colony is over for the season, the drones are expelled from the hive and die, so that only the workers and the queen remain in the hive throughout the year.

The body of a Bee, consisting of the HEAD, THORAX, and ABDOMEN, is entirely enclosed by the CUTICULA which is formed as a secretion by a layer of cells lying just underneath. This chitinous layer is quite rigid and affords protection and support for the enclosed living tissues of the animal. It is comparable to the exoskeleton of the Crayfish and Grasshopper.

The external structure of the worker is somewhat different from that found in either the drone or the queen. The body of the drone is noticeably larger than that of the worker, and has a broad, heavy abdomen which lacks a sting. The eyes are very large. The body of the queen resembles that of the worker in general contour, but it is larger and the abdomen is more elongated. The metathoracic legs of the queen and drone are also slightly modified. We may now consider in detail the various structural features as found in the worker. (W. fs. 214, 216.)

1. *Head*

It is generally believed that the head of the Bee is composed of six segments. However, the segmentation even in the embryonic condition is not entirely clear and, in the adult, segmental lines are not present. Attached to the head are several highly specialized structures and appendages which may be summarized as follows (W. f. 215) :

(a) A pair of large COMPOUND EYES which protrude from either side of the head. These are essentially similar in structure to those noted in the Grasshopper. Three other tiny, simple eyes (OCELLI) are situated near the median line of the 'forehead.'

(b) A pair of ANTENNAE which are attached to the anterior surface of the head and project forward and ventrally. They are jointed structures which serve as very important sense organs.

(c) A dome-shaped portion, the CLYPEUS, of the anterior wall of the head, which lies just below the points of attachment of the antennae. The upper lip, or LABRUM, is attached to the lower edge of the clypeus.

(d) Below the labrum is an unpaired, fleshy structure, the EPIPHARYNX, which is apparently an organ of taste.

(e) A pair of jaws, the MANDIBLES, which are attached, one at either end of the labrum. The MOUTH opens between the mandibles. When closed, the mandibles lie over the labrum and epipharynx so that these structures cannot be seen when the head is

viewed from the front. When open, the mandibles project ventrally and disclose the underlying structures.

(f) Projecting below the mandibles and attached to the ventral surface of the head is the prominent feeding organ, or PROBOSCIS, composed of several separate structures, namely: (a) a long, median, flexible TONGUE (GLOSSA) with a spoon-like tip (LABELLUM); (b) a pair of jointed LABIAL PALPS which lie next to the tongue; and (c) a pair of MAXILLAE situated lateral to the labial palps.

The mouth parts of the worker are used in many ways, and their structure is such that they are adapted for sucking nectar from flowers and for chewing solid materials, such as pollen grains and wax. The Bee, in collecting nectar from flowers, brings together the maxillae and the labial palps, lying on either side of the tongue, to form a tube which encloses the tongue, and in which the latter can be moved back and forth. The drops of nectar are first collected on the hairs which cover the tongue. Then they are forced upward by the movements of the tongue and by suction from the pharynx.

2. *Thorax*

The thorax consists of three segments, each of which bears a pair of legs. These are known, beginning anteriorly, as the PROTHORACIC, MESOTHORACIC, and METATHORACIC segments. The paired legs are named in accordance with the segment to which they are attached. The mesothoracic and the metathoracic segments each bears a pair of wings in addition to the pair of legs. The wings consist of a thin, secreted, chitinous material supported by tubular, vein-like structures. The two wings on the same side of the body may be fastened together by means of a row of hooks which are present on the anterior margin of the hind wing, and which can be inserted in a receptacle on the posterior margin of the anterior wing. When the Bee is flying, the wings are widely extended. When at rest, the wings are drawn close to the body on each side. Both the wings and the legs are operated by very powerful muscles which lie in the thoracic cavity. (W. f. 216.)

STRUCTURE AND FUNCTIONS OF THE LEGS. The three pairs of legs of the Bee are beautifully adapted for the various necessary types of work. They are, indeed, to be ranked among the most remarkable structures that are found in the Insects, or for that matter in any other group of animals. The fundamental structure

of the Bee's legs is typical of Insect legs in general, such as we have seen in the Grasshopper. Each consists of five segments, which, beginning with the one attached to the body, are named as follows: COXA, TROCHANTER, FEMUR, TIBIA, and TARSUS; the last is itself made up of five parts, the first of which is known as the BASITARSUS. The coxa and trochanter are comparatively small and lie close to the body; the femur, tibia and tarsus, therefore, comprise the major portion of the leg.

Prothoracic Legs. The femur and tibia are covered with characteristic long BRANCHED HAIRS, a few of which may also be found on the coxa and trochanter. These hairs aid in gathering pollen. On the outer surface of the tibia, just above where it joins with the tarsus, is a stiff brush of curved bristles, known as the POLLEN BRUSH, which is used to brush the loose pollen grains. Attached near by, to the inner side of the tibia, is a flattened, movable, spine-like structure, the VELUM, which somewhat resembles in shape the blade of an old-fashioned razor. The velum joins with a crescent-shaped indentation, known as the ANTENNA COMB, on the inner side of the first joint of the tarsus, which contains a number of toothed structures as in a comb. The velum and the antenna comb form the ANTENNA CLEANER. The antennae, held in place by the velum, can be drawn through the curved antenna combs and cleaned in this way. On the outer edge of the large first joint of the tarsus, there is a fringe of stiff bristles which project a considerable distance beyond the surface of the leg. These bristles constitute the EYE BRUSH. The latter is used to brush the hairs which project in considerable numbers from the surface of the large compound eyes, and thus dislodge any foreign particles that may be lying among them. The next three joints of the tarsus are small and similar in structure, but the last joint is so fashioned as to enable the animal to cling to various types of surfaces. On this joint of the tarsus there is a pair of bilobed claws which bear tactile hairs. Between the claws is a comparatively large, fleshy structure, known as the PULVILLUS. This organ is glandular, and from it a sticky liquid is secreted which enables the animal to cling to a smooth surface. (W. fs. 216, 217.)

Mesothoracic Legs. On the distal end of the tibia, near the union with the tarsus, there is a long pointed spine, the POLLEN SPUR. It occupies about the same position as does the velum on the prothoracic leg. This structure is used to dislodge the pellets of

pollen from the pollen baskets located on the metathoracic legs. A pollen brush is also present. The tarsus of the mesothoracic leg, however, lacks both the antenna comb and the eye brush.

Metathoracic Legs. This pair of legs possesses a number of interesting adaptations. The tibia is modified to form a large cavity, the POLLEN BASKET, which runs the entire length of the segment. It consists of a depressed area on the outer surface, in which the pollen is placed. The pollen is held there by hairs which arise on the edges of the tibia and which curve over the edges of the underlying depression in such a way as to keep the pollen grains firmly in position. The distal end of the tibia, where it joins with the tarsus, has a series of spines which constitute the PECTEN. These fit into a special structure, the AURICLE, on the proximal edge of the tarsus. On the inner side of the basitarsus are the POLLEN COMBS, which consist of several rows of regularly arranged bristles. The latter are used to hold some of the pollen before it is transferred to the pollen basket.

3. Abdomen

Although the abdomen of a typical Insect consists of ten or eleven segments, the external divisions of the exoskeleton in the Bee show only six. Each segment consists of an enclosing band of the chitinous exoskeleton which, when seen in a transverse section, shows the same general plan of structure as is found in the abdominal segments of the Grasshopper, with a dorsal plate, or TERGUM, and a ventral plate, or STERNUM. The separate exoskeletal rings are connected and articulated with each other by the flexible end tissues so that a considerable movement may be brought about by the action of the abdominal muscles. The sterna on the four posterior segments possess a pair of ventral openings which are connected with the internal wax glands, and through which the wax is secreted.

At the extreme posterior end of the abdomen, enclosed within the body wall, is a very complex organ for defense, the STING. There is an elongated, chitinous rod, the SHEATH, and a pair of DARTS with saw-toothed edges, one of which lies on either side of the sheath. Laterally, there is a pair of fleshy, hair-covered structures provided with sense organs, the FEELERS. The feelers locate a favorable region on the animal that is being attacked, and then the sheath with the darts is forced down into the tissues at the spot

selected. There are large muscles, attached to the proximal end of the sheath structure and also to the abdominal wall, which, by their contraction, bring about the movement of the sheath and darts. When the darts have been forced into the tissues, there is an injection through them of poisonous material. The latter is formed in convoluted, tubular structures, the POISON GLANDS, which secrete the poison into an enlarged portion of the tube, known as the POISON SAC. From the sac a tube leads down along the sheath. The poison is composed of an acid and an alkali, each being secreted by a definite region in the poison glands. It is stated that it is generally fatal for the Bee to use the sting, for when the darts and the sheath have been forced into the tissues of the other animal, it is very rarely that they can be dislodged without tearing off the posterior end of the abdomen of the Bee. (W. f. 218.)

B. ORGAN SYSTEMS

The general plan of arrangement of the various organ systems of the Bee is fundamentally the same as described in the study of the Grasshopper.

1. *Nutritive System*

The tubular alimentary canal is differentiated to form a number of interesting structures and is adapted for the intake of both liquid and solid foods. Connecting with the mouth cavity is the esophagus which is a small, undifferentiated tube running from the mouth entirely through the thorax and into the anterior end of the abdomen. Here it enlarges to form the CROP, or HONEY SAC. By means of this organ the Bee is able to store temporarily a considerable quantity of nectar. When the hive is reached, the nectar in the honey sac is regurgitated and placed in the cells to form honey as described below.

At the posterior end of the honey sac there is a short, stalk-like connection (proventriculus) which leads into the true stomach (ventriculus). The proventriculus contains four lips which are regulated by special sets of muscles to open and close them as needed. The stomach is lined with a layer of endodermal cells which secrete the digestive enzymes. Other cells in this lining layer are absorptive, and a certain amount of the digested food is absorbed from the stomach by them and passed into the blood stream. The unabsorbed, partially digested food passes from the

stomach into the small intestine. This organ is much smaller in diameter, but the walls have the same general structure as those of the stomach. Here the remainder of the food is digested and then passed into the blood. The small intestine enlarges posteriorly to form the RECTUM which opens to the exterior on the last abdominal segment.

2. *Respiratory and Vascular Systems*

The respiratory organs of the Bee consist of a complex system of thin-walled air tubes, or TRACHEAE, which ramify through the body tissues. These tracheal tubes open to the exterior through ten pairs of breathing apertures, or SPIRACLES, which are situated on the right and left sides of certain of the thoracic and abdominal segments. There are three pairs of spiracles on the thorax and seven pairs on the abdominal segments. The first two pairs on the thorax and the last pair on the abdomen are hidden from view by overlapping portions of the body wall. The spiracles open inside the body into the LONGITUDINAL TRACHEAL TRUNKS which extend along either side of the body, and from which the finer ramifying tracheae arise. In the anterior end of the abdomen, the tracheal trunks are very large and constitute definite AIR SACS, which, when filled with air, are supposed to aid the Bee in flight by lowering the specific gravity of the animal. There is a definite expansion and contraction of these air sacs, possibly corresponding somewhat to the respiratory movements of the higher Vertebrate animals.

This method by which the Insect tissues obtain their supply of oxygen is very efficient. The air containing oxygen comes into direct contact with the body tissues. There is, therefore, no need for a supplementary system to transport the oxygen to the cells, such as is found in the circulatory systems of other animals. As might be expected from this, the vascular system of the Insect does not show so great a development of the closed vascular system as in some of the less complex animals, such, for example, as the Earthworm, but opens freely into large sinuses and connecting channels which occupy considerable portions of the body spaces.

The only blood vessel in the Bee is the DORSAL BLOOD VESSEL, which extends almost the length of the body in a median line just below the dorsal body wall. The posterior part of this vessel, lying in the abdomen, is differentiated to form the HEART. The

latter consists of a linear series of four muscular compartments, known as the VENTRICLES, each of which possesses a pair of openings, the OSTIA. The heart lies in a blood space, the PERICARDIAL SINUS, and the general relations between these structures are similar to those observed in the Grasshopper. The dorsal vessel, of which the heart is a modified portion, continues posteriorly a short distance from the heart and finally ends blindly in the abdomen. Anteriorly this vessel passes into the head region where it gives off the blood to the tissues.

The course of the circulation of the blood is as follows. The blood which has been received in the pericardial sinus passes into the heart through the paired ostia. By the contraction of the muscular walls the blood is driven anteriorly through the dorsal vessel. It passes from the latter in the head region; then moves posteriorly and ventrally after bathing various body tissues, and finally reaches the large ventral sinus, from whence it is carried dorsally through special channels into the pericardial sinus.

3. *Excretory System*

The excretory system of the Bee consists of a considerable number of long filamentous tubules, all of which open into the intestine near its anterior end. These are known as the MALPIGHIAN TUBULES. The specialized cells in these tubules come into close contact with the surrounding blood, and are able to take the liquid waste products from the blood. These liquid excreta, instead of leaving the body in a liquid form by special ducts, are passed into the intestine. Thus the intestine serves not only as an organ for the egestion of indigestible materials, but also as an organ for the excretion of metabolic wastes.

4. *Reproductive System*

MALE REPRODUCTIVE ORGANS. The male reproductive organs of the drones consist essentially of a pair of TESTES. These organs are made up of a great number of fine, coiled tubes, the SPERMATIC TUBULES, in which the sperm develop. In a testis, the spermatic tubules all connect at one end with a much larger coiled duct, the VAS DEFERENS, and this in turn empties into a still larger uncoiled portion, the SEMINAL VESICLE. Each seminal vesicle opens into a glandular structure, designated as the ACCESSORY GLAND. The glands from each side unite, and from this union the common

EJACULATORY DUCT arises which leads to the exterior through the COPULATORY ORGAN. The mature sperm, after passing from the testis through the vas deferens, may be stored for a time in the seminal vesicles, but eventually they pass on into the accessory gland where they are mixed with a secreted fluid. They are then ready to be passed out of the body of the male and transferred to the SEMINAL RECEPTACLE of the queen.

FEMALE REPRODUCTIVE ORGANS. Fully developed female reproductive organs are found only in the queen. The essential organs are a pair of large OVARIES in which eggs develop. The ovaries fill a large part of the abdominal cavity and contain eggs in various stages of development, the general arrangement being such that the most mature eggs are situated toward the posterior end. The eggs are carried away from each ovary by a short straight tube, the OVIDUCT. The oviducts from each side unite to form a common tube, the VAGINA, and opening into the latter is the SEMINAL RECEPTACLE, which contains sperm received from a male during the nuptial flight. The vagina opens to the exterior at the posterior end of the abdomen, near the sting. It is known that the queen can lay two kinds of eggs: (1) UNFERTILIZED EGGS, which develop into drones, and (2) FERTILIZED EGGS, which develop either into another queen, or into the sexually undeveloped workers. It is not known how this process is regulated.

5. *Development of the Bee*

When a colony of Bees becomes so large that the hive is crowded, a new queen is developed as described in the next section. Later, when the young queen has reached sexual maturity, the old queen leaves the hive, accompanied by considerable numbers of followers. This is known as SWARMING. The swarm eventually finds a suitable place in which to establish a new colony, and the routine of hive life again begins. Shortly after this the young queen emerges from the old hive and performs her NUPTIAL FLIGHT during which mating occurs high in the air with one of the drones. Returning to the old hive, the young queen is supplied with food by the workers and becomes practically an egg-laying machine. Each day she lays a considerable number of eggs, most of which are fertilized. The eggs are deposited by the queen in cells built by the workers, and there the eggs develop: the fertilized ones into workers, and the unfertilized into drones. The early devel-

opment of the egg of a Bee is similar to that of the Grasshopper.

METAMORPHOSIS. Before finally reaching the adult condition, Insects typically pass through a regular series of developmental stages, two types of which may be noted: (1) **INCOMPLETE METAMORPHOSIS**, such as was noted in the case of the Grasshopper, and (2) **COMPLETE METAMORPHOSIS**, which occurs in the higher orders of Insects, including the Hymenoptera to which the Bee belongs. The four stages in the metamorphosis of the Bee are known as the **EGG**, **LARVA**, **PUPA**, and **ADULT**. They may now be considered in the order named. The eggs, which are laid by the queen in specially prepared cells, are small, oblong bodies of a rather grayish color. After a few days there develops from each egg an elongated, worm-like organism, the **LARVA**. The larva, corresponding to the nymph stage of the Grasshopper, is the feeding stage, and during the early part of this period the embryos are supplied with a highly nutritious **BROOD FOOD** which is formed by the workers as a secretion from well-developed **PHARYNGEAL GLANDS**. Later a mixture of pollen and honey constitutes the food of the worker-larvae. Certain of the workers serve as nurses for the larvae, and see to it that the latter are supplied with a plentiful amount of food. The larval period lasts about five or six days, during which time the young embryo increases a great many times in size. Since the exoskeleton of a larva is chitinous and rigid, it is necessary that this be shed periodically and replaced with a larger size as growth proceeds. This molting, which takes place five times while the young Bee is in the larval stage, is of the same character as in the other Arthropoda.

At the end of the larval period, when a certain size has been reached, each embryo proceeds to spin a **cocoon** around itself. The cocoon is formed by the secretions of certain specialized **SPINNING GLANDS** which open near the anterior end of the body. The secretion, which is given off as a liquid, soon hardens, and the young Insect thus encases itself in a silky covering, the cocoon. The final (fifth) larval molt then occurs which inaugurates the 'resting' **PUPA** stage. No food is eaten during this time, and the animal inside the cocoon is practically rebuilt. The result is that the elongated worm-like larva is metamorphosed into the adult flying Insect. This remarkable process of metamorphosis takes about thirteen days for the workers and drones, but con-

siderably less for the queen. When the metamorphic changes have been completed, a substance is secreted by the pupa which dissolves a portion of the cocoon and permits the adult to emerge. In many Insects the adult condition lasts only a short time. It has as its chief function the reproduction of the species. No growth occurs in either the pupa or adult stages.

The process of egg laying and development continues until the hive becomes overcrowded. When this occurs the workers construct one or more queen-cells, and a fertilized egg is deposited in each by the queen. It is known that a larva which develops from one of these eggs is fed by the workers with a much richer type of food than are the other larvae. Apparently as a result of this the embryo, instead of becoming a sexually immature worker, develops into a sexually mature queen.

6. *Nervous System*

The nervous system shows a great similarity to that previously noted in the Crayfish and Grasshopper. Altogether there are nine ganglia in the central nervous system of the Bee. Two of these ganglia are located in the head, two in the thorax, and five in the abdomen. The first, or CEREBRAL GANGLION, constitutes the brain and is situated in the head above the esophagus. It is really a very highly developed nerve center — a true brain. Various branches are given off from it which run to the sensory organs of the head, particularly to the eyes. Lying in the head, below the esophagus, is the SUBESOPHAGEAL GANGLION, which is also an important center. The nerves of this ganglion innervate a number of the mouth parts. Of the two THORACIC GANGLIA, the posterior one is much the larger and gives off nerves which innervate both pairs of wings and also the mesothoracic and metathoracic legs. The prothoracic legs are innervated by nerves from the anterior thoracic ganglion. Of the five ABDOMINAL GANGLIA, the posterior one is very important in that it innervates the genital organs and the sting.

SENSE ORGANS. The Bee possesses a number of sense organs which are of a high type and capable of receiving various kinds of stimuli from the environment. (W. f. 215.)

(1) *Tactile Organs.* For the sense of touch, the Bee possesses HAIR ORGANS which are essentially fine projecting hairs of various sizes and shapes. They have their origin in the underlying sense

cells which, in turn, are connected by nerve fibers to the central nervous system. These sensory hairs are present in great numbers near the tip of each antenna.

(2) *Organs of Taste and Smell.* Although the experimental evidence is not conclusive, it is generally held that the senses of taste and smell are located in tiny surface depressions, or pits, known as the **SENSE PORES**, which are present on the base of each antenna, on the mandibles, and on various head regions. Sense organs of this same structural type and which presumably function in the same way are also found on the legs, the bases of the wings, and the sting. Each of these depressions is connected with the central nervous system by a nerve fiber which begins in a special sensory area at the base of the cavity.

(3) *Other Sense Organs on the Antennae.* It is known that there are at least seven different kinds of sensory end organs localized on each antenna of the Bee. It is clearly apparent therefore that various types of external stimuli must be received by these end organs. Of one kind of end organ alone, the **SENSE PLATE**, there are about 2500 on the antennae of the queen, 5000 on the worker, and 30,000 on the drone; while the total number of sensory nerve cells present in one antenna of the drone has been estimated at 500,000. It is, of course, a very difficult problem to determine the exact location on the antennae of any particular sense reaction.

(4) *Organs of Sight.* The Bee possesses two large **COMPOUND EYES**, one on either side of the head, and three simple eyes, or ocelli, which are situated on the dorsal wall of the head, close to the median line. The compound eyes are similar in structure to those found in other Arthropoda. Each eye is made up of several thousand independent visual units, the **OMMATIDIA**. Projecting from the surface of the compound eyes, and arising from between the ommatidia, are a large number of hairs which apparently are protective in function. Pollen grains and other débris, which lodge between the hairs, are removed by the eye brushes on the prothoracic legs, the structure of which has already been noted. The ocelli are regarded as simple eyes because each consists of one visual unit which is believed to be similar in function to a single ommatidium of the compound eye. Both the compound eyes and the ocelli are innervated by nerves connecting with the cerebral ganglion.

C. ACTIVITIES OF THE WORKERS

Whereas the queen and the drones are concerned only with reproduction, there are many essential activities of the colony which are carried on by the workers. These activities include the building of the honeycomb, the gathering and preparation of pollen for food, the collection of the nectar from the flowers, the manufacture of honey from the nectar, and the general care of the hive. The latter comprises the cleaning, warming, ventilation, and guarding of the hive as well as painting the interior with bee glue which is secured from various plants. It is believed that the workers also determine when a hive is getting overcrowded. If such occurs, they construct the special queen-cells, noted above, in which the new queens are developed. In the collection of various substances from the flowers, the worker Bees incidentally transfer pollen from one plant to another, thereby bringing about cross pollination which, at least in many cases, is essential for the plants. (W. f. 219.)

We may now discuss some of the activities of the workers in more detail. When it is desired to form wax for building the comb, the Bees eat a great deal of honey and then remain quiet for a time, hanging in great numbers from the top of the hive. The honey is digested and assimilated, and a large part of it then used in the formation of the wax which is secreted by wax glands. These are located on the sterna of the last four abdominal segments. The wax flakes thus formed are removed from the wax pockets and then mixed with saliva and kneaded by the mandibles. When the proper consistency has been attained, it is deposited in just the right place in the comb which is under construction. The cells which compose a honeycomb are generally six-sided. It is a question as to whether these cells, when first formed by the Bees, are hexagonal or circular. Some authorities believe the latter to be the case, and that the six-sided cell arises as a result of the equal pressure of the surrounding cells.

The cells in a honeycomb are named, in general, according to the use which is made of them. As generally described there are six types of cells, as follows: QUEEN-CELLS, DRONE-CELLS, WORKER-CELLS, HONEY-CELLS, TRANSITION-CELLS, and ATTACHMENT-CELLS. The largest of these are the queen-cells. The drone-cells are the next in size, and the smallest cells of all are the worker-cells. The

honey-cells and the worker-cells are practically the same size and both of these types may be used for storing the honey. The attachment-cells are irregular in shape, and serve to attach the mass of the honeycomb to the sides of the hive.

The workers obtain various substances from the flowers. In the first place, they collect the nectar which is secreted in a liquid form at the base of the flower. This is secured by the long tongue in connection with certain mouth parts as previously described. It is taken into the body and temporarily stored in the honey sac. When the hive is reached the nectar is regurgitated and placed in the cells. These are not capped at once, and certain workers, by the vibration of their wings, cause the evaporation of a considerable part of the water in the nectar leaving a concentrated syrup which is honey. The flavor of honey depends upon the flowers from which the nectar was collected. Some of the flowers which supply the nectar for the best honey are those of White Clover, Buckwheat, and Alfalfa.

In addition to the nectar for honey manufacture, the Bees gather great quantities of pollen which constitutes one of their principal foods. Pollen is rich in nitrogenous compounds which are not present in the honey, and it is therefore necessary that the Bees have it as the basis of their food. Another material that is collected from various trees is bee glue, or PROPOLIS, which is a gummy, resinous substance. The Bees use it to cover the interior of the hive and to fill the cracks.

There are various matters of sanitation that must be looked after if a hive is to be kept in a healthy condition. This is due to the fact that there are so many Bees living in close quarters. Any waste materials or dead animals are removed by workers which are delegated for that purpose. Fresh air must also be supplied. This is accomplished by certain of the workers who stay at the entrance of the hive and draw in a current of fresh air by keeping their wings in motion. Other workers act as sentinels at the entrance and so guard the hive.

III. INSECTS IN GENERAL

A. POLYMORPHISM IN INSECTS

In the study of the Bee it has been seen that a certain amount of structural differentiation exists between the queen and the

workers, both of which are potentially female animals. Such differentiation existing between the different members of the same species constitutes a type of POLYMORPHISM. This phenomenon is shown to the greatest degree in certain species of the Ants, in which the polymorphism, just as in the Bee, is exhibited for the most part by the female individuals. Thus there are commonly found in an Ant colony the sexually mature queen and a series of sexually immature female animals, such as the large and small workers, soldiers, and various intermediate forms. The structure of these forms has become variously modified so that they are better adapted for their particular functions. For example, the mandibles of the soldiers are large and powerful.

Many other species of Insects are found associated with Ants in their nests as guests, parasites, etc. An interesting example of this condition is figured in the Frontispiece. In this case, a worker Ant (*Lasius*), having returned to the nest from a successful foraging expedition, is shown in the process of feeding another worker a drop of the collected nectar by regurgitation. A tolerated guest, the primitive Insect, *Ateleura*, is near at hand waiting for a chance to secure the food for itself.

B. ECONOMIC IMPORTANCE OF THE INSECTS

It would be hard to overemphasize the economic importance of this amazing group of animals. Thus it has been estimated that the annual losses in the United States alone, due to the destruction of plant and animal products on the farms by various species of Insects, amount to more than three-quarters of a billion dollars.

It is usually during the larval or nymph stage of Insects that damage is done to vegetation. In general the eggs of an Insect are laid upon the material best suited for the larvae to feed upon. In many cases as, for example, in the Moths, the eggs are attached to the leaves of plants, and when the larvae hatch, they immediately begin to destroy the leaves. If they are present in sufficient numbers, as frequently happens, the tree will be stripped of its foliage and in many cases actually killed. (W. f. 262.)

The estimate of Insect depredations given above does not include the incalculable losses sustained by the human race as the result of insect-borne diseases. The germs of such diseases are sometimes carried *externally*, attached to various parts of the body as, for example, in the case of the common House-fly which may

spread typhoid, tuberculosis, and other serious diseases in this manner; or in many cases the Insect may carry the germs of the disease *internally* and transmit the latter by injecting the germs directly into the body of the victim as, for example, in a certain species of the Mosquito which transmits Malaria in this manner. (W. pp. 339-342.)

On the other hand, it should be noted that there are a number of species of Insects, such, for example, as the Honey Bee, the Lac Insect, and the Silk Worm, which contribute very materially to man's welfare. Commercially the most important is the Silk Worm, and it is from the cocoon of this animal, spun at the end of the larval period, that the silk of commerce is obtained. This is done by unwinding the silky thread which makes up the cocoon, after having first killed the pupa by placing in boiling water. It is stated that the length of thread that may be unwound from an average cocoon is 1526 feet, or somewhat more than one-fourth of a mile. The larvae of many other Insects spin a cocoon, but the 'silk' is without value either because it is not of good quality or because it cannot be unwound. (W. f. 267.)

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XIV. CLAM

THE Mollusca constitute a large important, and structurally aberrant phylum of Invertebrate animals which includes such commonly known forms as the Clam, Oyster, Snail, Slug, Squid, and Octopus. These animals, although notably complex, exhibit in their bizarre adult organization very few morphological features by which they can be closely linked to any other group of animals. Like the Sponges and the Echinoderms, they apparently portray a comparatively isolated structural arrangement. Furthermore the differences between various members of the phylum are unusually marked. This fact may be noted when one compares, for example, the structure of the sedentary Clam with that of a free-swimming Squid. All Molluscs, however, are triploblastic; they show no evidence of segmentation in the adult condition, and the coelom is greatly reduced. Bilateral symmetry is present to a greater or less degree. Two characteristic molluscan features are present in some form or other in most species, namely, a muscular structure, known as the FOOT, and a calcareous SHELL.

The study of a representative of the Mollusca is important, not only because of the unique structural features which are there shown, but also because of their importance from the economic standpoint. A great many species, such as the Oyster and Clam, are edible. The shells of some species, such as the fresh-water Mussel, are the basis of the pearl button industry, and true pearls are also formed by Molluscs. Altogether the income from the shellfish industries amounts to many millions of dollars annually.

A. EXTERNAL STRUCTURE

For our present study, either the common, marine Hard Clam, or Quahaug (*Venus*), or the fresh-water Mussel (*Unio* or *Anodonta*), may be used. All these forms are very similar in general structure.

The Clam is enclosed in a secreted SHELL, largely composed of calcium carbonate. The shell is made up of a right and left half, each of which is spoken of as a VALVE. The Clam and other Molluscs which have two valves are commonly designated as BI-

VALVES, in distinction to other types of Molluscs, like the Snails, in which the shell is single and which, therefore, are termed UNIVALVES.

In the Clam, the two valves are hinged together along one edge which is regarded as the dorsal surface of the animal. Definite lines of growth in the form of concentric ridges can be noted on the surface of the shell. These lines radiate from an elevated portion, or beak, of each valve, known as the UMBO, which typically points toward the anterior end of the animal. From these lines of growth the age of the animal at various stages during its development can be definitely determined. Holding the Clam with the hinged, or dorsal, side up and with the umbo, or anterior, end pointing away, we are able definitely to orient the animal and designate the right and left valves.

The two valves of the shell are connected inside by two large internal muscles, one of which is situated near the anterior end (ANTERIOR ADDUCTOR MUSCLE) and the other in the same relative position near the posterior end (POSTERIOR ADDUCTOR MUSCLE). These two muscles are very strong and are attached directly to the two valves, so that when the muscles are contracted the valves are drawn tightly together. In opening a Clam, the point of a knife blade can be inserted between the valves at some point along the ventral edge, and the adductor muscles cut. When these muscles have been cut the valves will spring apart somewhat, owing to the action of certain ligaments in the hinges. (W. f. 49.)

B. ORGAN SYSTEMS

Both valves of the shell are lined, except at the extreme edges, by a thin secreting tissue, known as the MANTLE. With care the mantle can be separated from the inside of the shell, detached along the dorsal surface, and thus all the internal organs of the Clam, enclosed within the two folds of the mantle, can be removed from the shell. Or, stated in another way, the internal organs of the Clam may be said to be enclosed by, first, a heavy external shell and, second, a thin internal layer of living tissue, the mantle, which lies just within and attached to the shell. The cells of the mantle tissue form the shell as a secretion, and the concentric lines of growth indicate the successive positions of the secreting surface of the mantle.

The internal structure of the Clam can be studied to advantage

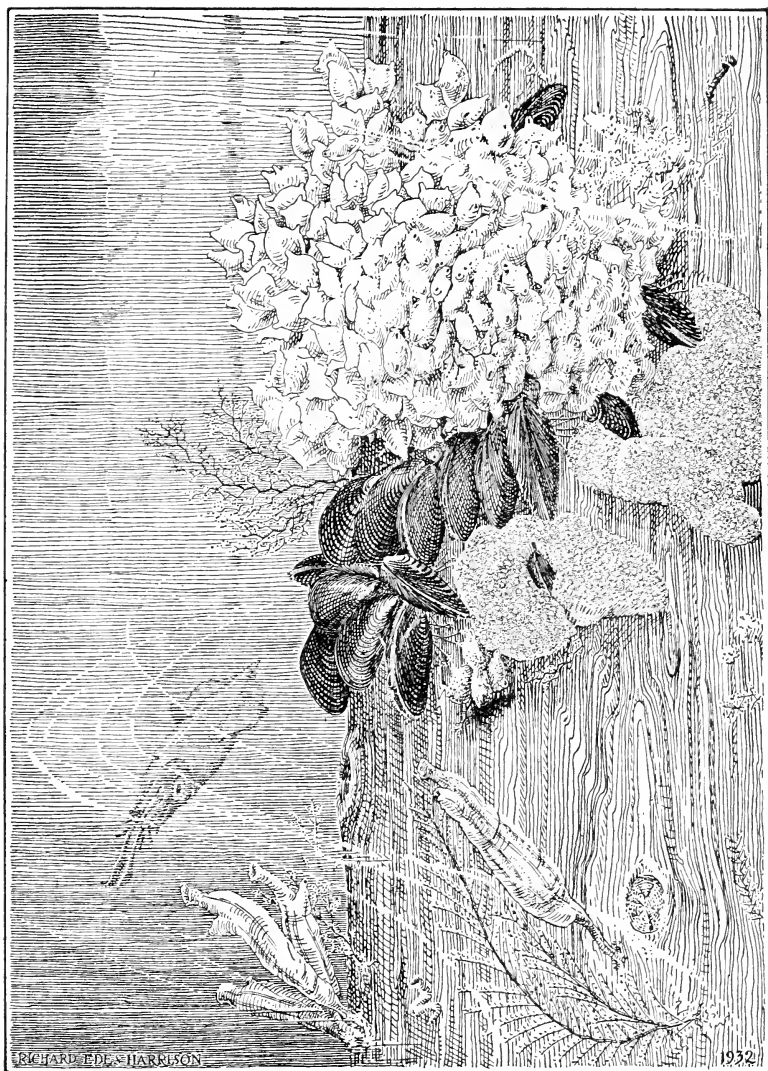


FIGURE 9

This drawing shows several marine animals growing on a wharf piling, and the free-swimming Squid, a highly developed Mollusc, in the water at the lower left. Attached to the piling in the center are several black-shelled Molluscs (*Mytilus*), above which is a Tunicate, *Molgula*. The stalked Tunicate (*Ciona*) is shown below. *Amaroucium*, a colonial Chordate, is attached to the right of *Mytilus*. The Coelenterate, *Obelia*, projects to the left above *Mytilus*; and *Pennaria*, at the lower right-hand corner. Adapted from a group at the American Museum of Natural History,

by carefully removing the left valve of the shell, together with the left fold of the mantle. This discloses the various organs of the body, which consist of the VISCERAL MASS, GILLS, and FOOT. All these lie in the space between the folds of the mantle, termed the MANTLE CAVITY. At the posterior end of the animal, the edges of the mantle form two definite openings, the INHALENT SIPHON and the EXHALENT SIPHON, through which a current of water enters and leaves the mantle cavity. (W. f. 49.)

The visceral mass, composed of a number of organs which will be considered in detail later, lies between and somewhat dorsal to a line connecting the prominent anterior and posterior adductor muscles which were cut through in removing the left valve. Ventrally the visceral mass merges into the heavy muscular FOOT. The latter is an organ of locomotion which may be protruded between and beyond the ventral edges of the valves. A pair of GILLS is present on each side of the visceral mass. They are attached dorsally and hang down into the mantle cavity, reaching almost to the edge of the mantle.

1. *Nutritive System*

The MOUTH OPENING is at the anterior end of the body and lies just posterior to the anterior adductor muscle. Surrounding the mouth are two pairs of elongated, ciliated structures, the LABIAL PALPS, which are in close connection with the anterior end of the gills. Leading dorsally from the mouth there is a short ESOPHAGUS which opens into the anterior end of the stomach. The anterior wall of the STOMACH lies close to the posterior wall of the anterior adductor muscle. The stomach is a rather large, undifferentiated sac. Leading from near the middle of the ventral wall of the stomach is a long, greatly coiled INTESTINE which, after proceeding ventrally and posteriorly down into the region of the foot, makes a number of coils and then turns dorsally and continues this course until it is above the dorsal wall of the stomach. At that point it makes a right angle turn and runs directly posteriorly until it ends at the anal opening which lies just a little posterior to the posterior adductor muscle and near the exhalent siphon.

The HEART of the Clam lies in a PERICARDIAL CAVITY situated in the median line, and just below the dorsal body wall. Strangely enough, the intestine passes into the pericardial cavity and directly

through the heart. On either side of the stomach is a digestive gland, or **LIVER**, which secretes certain digestive fluids that are emptied into the stomach through two slender ducts. The intestine, near the basal portion of the foot, is surrounded by the gonads.

Certain phases of the Clam's nutrition are unlike those studied in other animals. In the first place, in securing food, the gills, which ordinarily function solely for respiration, play a prominent part. A constant current of water is brought into the mantle cavity in which the gills are suspended. This water current is due to the action of cilia on the gills. The current is drawn into the mantle cavity through the ventral inhalent siphon, and, after passing through the gills, leaves the animal through the dorsal exhalent siphon. As the water passes through the gills small living organisms and also very small particles of organic material, which may be utilized for food, are strained out from the water. The food materials are then carried by the action of special gill cilia to the anterior end of the body where they come into contact with the ciliated labial palps around the mouth. The cilia of the latter beat in such a manner as to sweep the particles into the mouth opening.

The food thus taken into the mouth passes through the esophagus, into the stomach, and then into the intestine, through the walls of which the digested food materials are absorbed and passed to the circulatory system. The indigestible materials pass on through the intestine and are egested at the anal opening. They are carried to the exterior through the exhalent siphon by the action of the out-going water current.

2. *Vascular System*

The Clam has an efficient vascular system which, although somewhat different in details, consists of the same fundamental parts noted in the animals previously studied. Certain features of the vascular system recall those found in the Crayfish. The heart lies in a membranous chamber, the **PERICARDIAL CAVITY**, and consists of a large muscular **VENTRICLE** through which the intestine runs. Leading from the anterior end of the ventricle is the **ANTERIOR AORTA**, and from the other end, the **POSTERIOR AORTA**. An enlargement of the posterior aorta, soon after leaving the heart, is the **BULBUS ARTERIOSUS**, which acts as a reservoir for blood forced

back towards the heart by a contraction of the muscular foot. These are the two main arteries of the body and they give off branches which supply all parts of the body. Attached to the ventricle are two thin-walled chambers, the AURICLES, one on the right side and one on the left side. These project ventrally and connect with the EFFERENT BRANCHIAL VESSELS from the gills. The auricles pass the blood which they receive into the ventricle. In the tissues of the body are numerous blood SINUSES similar to those previously noted in the Arthropoda. The main vein of the Clam, the VENA CAVA, lies ventral to the pericardial cavity. The blood from the various regions of the body collects in it, and is then forced through the kidneys and from them carried by the AFFERENT BRANCHIAL VESSELS to the gills. (W. f. 49.)

There is one morphological feature of the Molluscan circulatory system which shows a higher type than any hitherto studied, and that is the presence of auricles in the heart. The blood instead of returning to the pericardial cavity and then being taken directly into the ventricles of the heart through the ostia, as in the Crayfish, is received from the branchial vessels by the auricles which are connected with the ventricle. Therefore, although the pericardial cavity of the Clam surrounds the heart, it does not function as a receiving organ for the blood going to the heart.

FUNCTIONAL. The general course of circulation of the blood is as follows. Beginning with the ventricle of the heart, the blood is forced either anteriorly or posteriorly through the anterior aorta or the posterior aorta. After passing through the tissues, largely by means of the sinuses, it is finally collected into the large vena cava. This vein is connected directly with the kidneys, so that the blood is next conducted through these excretory organs and during this passage the liquid metabolic wastes are removed. After passing through the kidneys, the blood reaches the gills by way of the afferent branchial vessels. In the gills the respiratory interchange of carbon dioxide and oxygen takes place. The blood, now freed both from the liquid nitrogenous wastes and the carbon dioxide and carrying a fresh supply of oxygen, passes through the efferent branchial vessels into the right or left auricle of the heart, and then into the ventricle, from whence it is driven again over the same course. It should be stated that a small portion of the blood passes from the heart, through a branch of the anterior aorta, into the tissues of the mantle which also serves as an organ of respira-

tion. This blood after passing through the mantle is returned directly to the heart.

3. *Respiratory System*

The chief respiratory organs of the Clam consist of two pairs of gills which, as we have seen, lie in the mantle cavity on either side of the visceral mass. Each gill consists of two ciliated, elongated, perforated sheets of tissue, the LAMELLAE, which are separated a short distance from each other by regularly arranged vertical rods, the INTERLAMELLAR JUNCTIONS. The edges of the lamellae, with the exception of the dorsal surface, are fused together. Each gill may be compared in its structure, therefore, to a very narrow, elongated bag, the top, or dorsal side, of which is open. The cavity of the bag is divided by the interlamellar junctions into a number of vertical compartments, the WATER TUBES.

The lamellae of the gills are made up of a large number of definitely arranged units, the GILL FILAMENTS. These run parallel to the interlamellar junctions and give the gill a distinct dorsoventral striation. The filaments are connected by INTERFILAMENTAL JUNCTIONS. Regular openings, the OSTIA, are situated between the gill filaments so that water can pass through them and into the spaces, or water tubes, between the lamellae.

The gill filaments are covered with ciliated epithelial cells, the cilia of which exhibit a coördinated, beating movement. This causes a continuous current of water to be drawn into the mantle cavity through the inhalent siphon. The water then flows through the ostia of the gills into the water tubes, thence dorsally into a longitudinal SUPRABRANCHIAL CHAMBER which opens posteriorly into the exhalent siphon. During the passage of the water through the gills, the interchange of carbon dioxide from the animal for oxygen in the water takes place through the thin walls of the gills. The cilia on the gills exhibit considerable differentiation both in size and function. The beat of some of them is such as to produce a current of water carrying the food particles toward the labial palps which convey them to the mouth.

4. *Excretory System*

The excretory organs of the Clam consist of a pair of KIDNEYS which lie below the pericardial cavity and extend slightly beyond it posteriorly, nearly to the adductor muscle. Each kidney con-

sists of two parts: first, a glandular portion which lies ventrally and, second, a storage portion, or **BLADDER**, which lies dorsal to the glandular portion and in close contact with the ventral wall of the pericardial cavity. These two portions are separated for a considerable distance by a thin wall of tissue, but posteriorly they are in communication through a small opening. The glandular portion of the kidney opens into the pericardial cavity at the anterior end through a small duct, the **RENO-PERICARDIAL APERTURE**. The bladder opens also anteriorly through a tiny opening, the **RENAL APERTURE**. The nitrogenous wastes collected by each kidney leave through the renal aperture and thence are swept out of the animal with the current of water through the exhalent siphon. (W. f. 49.)

The kidney apparently functions in two ways. In the first place, it is believed that certain wastes, present in the pericardial cavity, can be drawn directly into the glandular portion of the kidney by the cilia lining the tube which opens into the pericardial cavity. However, the greater portion of the work of excretion is done by the glandular portion of the kidney in taking the liquid wastes from the blood passing through it. It is generally stated that the kidney of the Clam represents a greatly modified type of nephridium such as was noted in the Earthworm. Since the pericardial cavity of the Clam represents the greatly reduced coelom, we have, therefore, much the same situation as in the Earthworm with the nephridium opening directly into the coelom.

5. *Reproductive System*

In most species of Clams the sexes are separate, although a few species are hermaphroditic. The general structure of the male and the female gonads is much the same. They are paired organs, situated in the dorsal portion of the foot. The intestine which runs through this region is more or less surrounded by the gonads.

The eggs produced in the ovaries of the female pass out through a small opening, known as the **GENITAL APERTURE**, which lies almost directly ventral to the anterior end of the pericardial cavity and just below the renal aperture. In the fresh-water Mussel the eggs then pass to the gills. The particular portion of the gills which retains these eggs — it varies in different species of Mollusca — is known as a **BROOD POUCH**. The sperm of the male, produced in the testes, passes out through a similar opening. The sperm, how-

ever, are conveyed entirely away from the body of the male with the current of water passing out through the exhalent siphon. Some of the sperm thus discharged into the surrounding water are drawn into the mantle cavity of the female by the current of water which is continually taken in through the inhalent siphon. This water containing the sperm bathes the gills of the female, and there the sperm come in contact with the attached eggs and fertilization occurs.

The fertilized eggs develop in the gills of the mother, and in some species remain there during the following winter. In all cases the eggs undergo a considerable period of development in the gills, and are then discharged into the water, where they begin their independent existence. The eggs of the Clam, when fertilized, undergo complete segmentation and pass through the various embryonic stages with which we are familiar. In the fresh-water Mussel there finally develops a parasitic stage, known as a GLOCHIDIUM, which is adapted for attaching itself to a fish by means of teeth-like structures which are present on the edges of the valves. When a fish comes in contact with the glochidium, the toothed shells snap shut in the fish tissues, and the embryo is thus attached to the body of the fish, where it stays for a time as a parasite. The skin of the fish grows over the glochidium, and it receives nourishment from the surrounding tissues. Finally, it liberates itself, falls to the bottom of the lake or stream and takes up its independent existence as a mature Clam.

6. *Nervous System*

The nervous system of the Clam departs somewhat widely in its structure from that of the animals previously studied. It consists of a number of paired ganglia situated in various regions of the body and connected by nerve cords. In the region just posterior to the anterior adductor muscle is a pair of ganglia, the CEREBRO-PLEURAL GANGLIA, one of which lies on either side of the esophagus. These ganglia are connected with each other by a nerve cord, the CEREBRAL COMMISSURE, which passes around the esophagus just before the latter opens into the stomach. Running ventrally and posteriorly from each of these ganglia is a nerve cord, the CEREBRO-PEDAL CONNECTIVE, which connects in the basal portion of the foot with a ganglion, known as the PEDAL GANGLION. This ganglion is really paired, but the two parts have become

almost completely fused so that externally the double nature is not clearly apparent. From each of the cerebro-pleural ganglia there is also another nerve cord, the CEREBRO-VISCERAL CONNECTIVE, which runs posteriorly and connects with the VISCERAL GANGLION situated on the ventral side of the posterior adductor muscle. The visceral ganglion has the same general structure as the pedal ganglion. These three paired ganglia with the connecting nerves constitute the main parts of the nervous system of the Clam. Peripheral branches are given off from the various ganglia, which innervate the near by organs.

SENSE ORGANS. In the Clam the sense organs are not so well-developed as in the Arthropoda. Possibly this is due to the fact that the Clam does not move rapidly and, therefore, does not have the same need of complex sense organs. It is interesting to note in this connection that in another class of the Mollusca, which includes free-swimming species like the Squid (fig. 9) and the Octopus, highly developed sense organs, such as eyes, are present. There are, however, in the Clam, two sense organs which should be noted. The first of these, known as the OSPHRADIUM, consists of a small area of pigmented epithelial cells which covers the visceral ganglion. It is believed that this organ, in some way, is able to determine the purity, possibly the oxygen content, of the water which is drawn into the mantle cavity. If the water which comes in is unsuitable, it presumably stimulates the sensory cells of the osphradium. Another sense organ, the STATOCYST, is situated near the pedal ganglion and consists of a small vesicle containing a calcareous body. It probably serves as an organ of equilibration. (W. f. 50.)

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XV. THE FROG AND VERTEBRATES IN GENERAL

THE animal kingdom is commonly said to be divided into the INVERTEBRATES and the VERTEBRATES. The basic distinction between these two groups may be said to be the presence in the latter of a dorsal supporting axis, the vertebral column, which is of paramount importance in its relations to the general supporting structures of the body and in the protection rendered to the spinal cord. It is evident, therefore, that the several metazoan phyla so far noted have consisted only of Invertebrates. The Vertebrates, on the other hand, belong to one phylum, the CHORDATA. This phylum also includes, in addition to the important vertebrate division, a small number of types which, for the most part, are aberrant structurally but possess, nevertheless, certain basic features which seem to link all of them together. These distinctive features may now be noted :

(1) A dorsal supporting axis, the NOTOCHORD, is always present either throughout life or, at least, during early development. The notochord is a rod-like structure which typically extends the entire length of the animal, dorsal to the alimentary canal, but it is subject to considerable variation in the different chordate groups. In the Vertebrates, the vertebral column develops in close relation to the notochord.

(2) A well-developed, TUBULAR CENTRAL NERVOUS SYSTEM which lies dorsal to the notochord and alimentary canal is present either during embryonic development or throughout life. It will be remembered that in the Invertebrates which possess a central nervous system, the nerve cord always lies ventral to the alimentary canal and is a solid cord, instead of a tube with a central cavity as in the Chordates.

(3) At some period in their life history the Chordates typically possess paired lateral openings, situated near the anterior end of the body, which connect the cavity of the pharynx directly with the exterior. These openings are known as GILL SLITS and, when functional, permit the water taken in through the mouth to pass

over the gill filaments, which are developed in or near the walls of the gill slits, and then to the exterior. In the aquatic Chordates, such, for example, as a Fish, this movement of the water is essential inasmuch as the exchange of gases necessary in respiration takes place as the water bathes the highly vascularized gill filaments.

Having noted the characteristic features of chordate structure we may now proceed to a consideration of the animal types which are usually included in this phylum. Four major divisions, or subphyla, of Chordata are recognized, the first three of which are interesting from the comparative standpoint, but otherwise unimportant. These are as follows:

A. **HEMICHORDATA.** A small group of marine animals, usually worm-like in appearance and with a proboscis, but which may show great variation. The best known representative of the Hemichordata is *Dolichoglossus* which is fairly common. It lives along the shore embedded in the sand or mud and secures its food in much the same way as the Earthworm, that is, by digesting the organic material from the débris which passes through the tubular alimentary canal. The notochord is short, the central nervous system not highly developed, but the paired lateral gill slits are prominent and functional. Colonial, deep sea species are known which reproduce by budding.

B. **UROCHORDATA.** This subphylum contains several rather common marine organisms which are commonly known as the Sea-squirts, due to their habit of ejecting a stream of water when disturbed. The mature individual of this group shows a degenerate condition as compared with the larva. The latter for a time during early development is a small, free-swimming, tailed form with well-developed Chordate features, somewhat closely resembling the larval, or tadpole, stage of the Frog in general body plan. It very soon attaches itself anteriorly to some solid object in the water and undergoes a marked structural regression, or metamorphosis, to form a sessile adult which lacks the tail, notochord, and central nervous system, but possesses many gill slits and associated organs which serve both for respiration and for the capture of food in somewhat the same way as in the Clam. The adult is enclosed by a peculiar covering, or tunic, which is the basis of the term **TUNICATE**, often used to designate this subphylum. It is stated that the tunic is largely composed of cellulose, and that this is possibly the only example in the animal kingdom of this



FIGURE 10

One of the most interesting of the many species of tailed Amphibians is the Axolotl (*Amblystoma mexicanum*). This species usually retains the large functional gills, as shown here, throughout life. Under other conditions, apparently endocrine in nature, metamorphosis occurs and the gills are lost. The animals shown are a white variety — a rare condition which has arisen in captivity. They have been bred in the Osborn Zoölogical Laboratory for several generations, and many of the embryos used in experimental embryology.

material which is so very abundant in plant tissues. Solitary types (*Ciona*, *Molgula*) and colonial types (*Amaroucium*) are abundant in marine waters as shown in figure 9. Reproduction may occur either sexually or asexually (budding). Alternation of generations is also known in some species.

C. CEPHALOCHORDATA. Only one genus comprising a few marine species are classified in this subphylum, but included among these is the important species *Branchiostoma lanceolatus*, more commonly known as *Amphioxus*, or the Lancelet. The importance of *Amphioxus* from the zoölogical aspect lies in its possession throughout life of structural features which link it closely with the true Vertebrates as well as with the Chordates. It is a small fish-like animal a few inches in length and is able to dart about quite rapidly when disturbed. The adult, however, usually lies vertically in a sand burrow with only the anterior end of the body projecting. As in the case of the Tunicates, noted above, food is secured from the water current which continually bathes the gills. *Amphioxus* lacks a definite head, jaws, and limbs. There is a dorsal fish-like fin which runs the length of the body in the median line, enlarges near the posterior end to form a wide caudal fin and continues forward ventrally for a short distance. There is no heart, but a well-developed system of blood vessels is present, some of which are contractile. The main flow of blood, which is towards the anterior end ventrally and towards the posterior dorsally, is similar to that of the Vertebrates. (W. f. 67.)

D. VERTEBRATA. We may now turn our attention to a consideration of certain general features associated with the Vertebrata, by far the most important subphylum of the Chordates, including as it does all the familiar animal types such, for example, as the Fishes, Frogs, Snakes, Birds, Rabbits, and Man. Certain important diagnostic features of this subphylum — in addition to the three fundamental Chordate characteristics — may now be briefly noted (W. fs. 94, 95):

(1) As indicated by the term VERTEBRATE and noted above, all these forms possess a backbone, or vertebral column. This important supporting structure is composed, except in the most primitive vertebrates, of a considerable number of bony segments, or VERTEBRAE, which develop in close relation to the unsegmented, cartilaginous notochord of the embryo and, usually, entirely supplant it in the adult.

(2) Vertebrate animals possess an internal supporting skeleton (ENDOSKELETON) composed essentially of living matter. The bones, tendons, cartilage and the very abundant connective tissues of all kinds constitute the endoskeleton. In addition to the vertebral column there are: (a) a brain case, or CRANIUM, in which special locations, the SENSE-CAPSULES, are present for the olfactory, optic, and auditory sense organs; and (b) supports for the appendages. Vertebrates have either a partial or complete EXOSKELETON composed essentially of non-living matter. Examples of the exoskeleton are to be seen in the scales of Fishes, the shell of a Turtle, the feathers of Birds, the hair, nails, hoofs, and claws of Mammals. Exoskeletal structures have previously been noted in our study of certain Invertebrates, but the bony endoskeleton of the Vertebrate is a new feature.

(3) The vertebrate limbs are restricted in number. There are never more than two pairs present, and in many cases there are less. Thus in certain Reptiles like the Snake, limbs are lacking. It appears that the five-fingered, or PENTADACTYL limb is to be considered as typical of the Vertebrates. The entire series of vertebrate limbs is regarded as homologous, and these range from the many-rayed fish fin to the limbs of certain Ungulates, like the Horse, which, as will be seen later, have retained only one functional digit on each limb.

(4) The blood of the Vertebrates contains a new type of blood cell, the red corpuscle. The color of these cells is due to the important respiratory compound, hemoglobin, which, in the Earthworm, is carried in the blood plasma, rather than in specific cells.

(5) Reproduction is always sexual. There is also an absence of hermaphroditism in the Vertebrates. The abandonment of both asexual reproduction and hermaphroditism appears to have been a comparatively recent step in the history of animal development. As a matter of fact, examples of both these discarded methods of reproduction are to be found in the lowest Chordates, as noted above.

In addition to the distinctive vertebrate characters, as just noted, attention should be called to the five important structural features, first noted in the discussion of the Earthworm, which are, in general, characteristic of all the higher Metazoa and which are well-exhibited by the vertebrate organism. These features it will be remembered are (a) the triploblastic condition with ecto-

derm, mesoderm, and endoderm present; (b) the segmentation of the body, which is internal in the Vertebrates; (c) the presence of a large coelom which, in the Vertebrates, consists of either a single cavity or of an anterior and posterior cavity; (d) the marked bilateral symmetry; (e) the still further development of the organs and organ systems. In the later and more extended consideration of the various phases of vertebrate organization, additional attention will be given to these features.

We may now note the animals included in the main divisions of the subphylum Vertebrata, the general characteristics of which we have considered in sufficient detail. The classification of this division of the animal kingdom does not offer the difficulties to the systematist which are frequently encountered in the much larger and more diversified Invertebrate groups, such as we have noted, for example, in the Insecta. Seven classes of Vertebrate animals are generally recognized, although some systematists prefer to place all the fish-like types into one class, and thereby reduce the total number of classes to five.

CLASS I. CYCLOSTOMATA. This is a small class, but nevertheless contains a number of fish-like species which are interesting to zoölogists because of certain primitive characters which seem to link them closely to *Amphioxus*. Thus (a) the notochord persists throughout life; (b) a cartilaginous endoskeleton develops, is functional, and never replaced by bone; (c) the circular mouth opening, with no jaws present, shows a striking resemblance to that of *Amphioxus*; (d) dorsal and caudal fins are present, but paired fins are lacking.

There are two subclasses recognized, namely, the Myxinoidea, or Hagfishes; and the Petromyzontia, or Lampreys. The Hagfishes are marine and frequently deep sea. The Lampreys may be found both in fresh and salt water. Several species of Lampreys are known of which the most common is probably *Petromyzon marinus*. The larval form of this species, known as *Ammocoetes*, is of unusual interest in various ways, but particularly because it resembles *Amphioxus* both in certain structural features and habits even more closely than does a mature *Petromyzon*. After early development it buries itself in the sand for a period of three or four years, during which time it feeds on fine particles of food drawn in through ciliary action, just as does *Amphioxus*. At the close of this period it metamorphoses into the typical adult. (W. f. 68.)

CLASS II. ELASMOBRANCHII. This class includes a number of species, some of which occur in great abundance in most marine waters. The Sharks, Dogfish (a species of Shark), and Rays, or Skates, belong to the Elasmobranchs. These animals show considerable advance over the Cyclostomes. Thus (*a*) the notochord is segmented, only partially persistent, and cartilaginous vertebrae have arisen; (*b*) a well-developed lower jaw is present and possesses modified scales which serve as teeth; (*c*) two pairs of lateral fins are found. (W. fs. 69, 70, 120.)

There are two subclasses of Elasmobranchs recognized, namely, the Selachii and the Holocephalii. The last named subclass is small in numbers and relatively unimportant from our standpoint, but considerable interest attaches to the Selachian group. It is very clearly divided into two orders, to the first of which belong all the many species of Sharks, and to the second of which belong the Skates and Rays. The Sharks are slender types, such as the Dogfish, with gill slits on the side, and with the body almost circular in outline as seen in transverse section, while the Rays and related forms are decidedly flattened dorso-ventrally and with the gill slits on the under, or ventral, surface. Thus they are perfectly adapted for living conditions on the sea-bottom. The common Dogfish, *Squalus acanthias*, is used a great deal for laboratory study in comparative anatomy as an important example of the lower Vertebrates. Among the Rays, all of which exhibit a number of typical features, the Torpedo is particularly noteworthy because of the amazing modification of certain muscles lying in the head region which permit them to accumulate charges of electrical energy sufficient to paralyze large animals.

CLASS III. PISCES. This is by far the largest and most important group of the 'fish-animals,' including, as it does, some 15,000 species of the so-called 'bony fishes,' among which are to be found practically all the more common fresh and salt water types, such, for example, as the Perch, Cod, Trout, and Salmon. Again considerable advances in organization over both the Cyclostomes and Elasmobranchs are to be noted. In fact the Pisces are often referred to as the 'true fishes.' Of outstanding importance is the fact that, for the first time, bone is developed in the endoskeleton. In many species of this class the skeleton is almost entirely ossified, while in others the original cartilaginous skeleton is only replaced in part. As a rule the notochord is entirely replaced by the seg-

mented, bony vertebral column. The external openings of the gill slits are covered, on each side of the body, by a fold of tissue, the OPERCULUM.

There are two subclasses recognized, namely, the Teleostomi and the Dipnoi. The last named subclass contains only a few species and these are comparatively rare, but are interesting because of the presence of either single or paired lungs. They are often known, therefore, as the Lung-fishes. The presence of functional lungs and certain other structural features as well as their habits of life would seem to indicate a close relationship to the Amphibia, the next higher class of Vertebrates. On the other hand, certain features, such as the persistence of the notochord, are regarded as more primitive in character. (W. f. 75.)

The very much larger subclass, the Teleostomi, is subdivided into four orders of which the last, the Teleostei, is the most important and includes most of the common species of bony fishes. Although the majority of species included show the typical spindle-shaped body with which we are all familiar, there are, nevertheless, found many varieties which depart widely from this type. As a matter of fact, the shape and general structural features are typically found to be in close harmony with the habits of life. The active swimming types of fishes, known to everyone, do not have much variation in structure, but keep close to the laterally-compressed, pointed spindle-shape which offers minimum resistance as the animals are driven through the water by their muscular swimming actions. (W. f. 71.)

The less active species present a considerable number of interesting structural variations. Thus, we may note the Sea-horse (*Hippocampus antiquorum*) which clings to objects with its peculiar tail and thus maintains a vertical position in the water while it pokes around the sea weeds with its long snout. The shape of the head of *Hippocampus* bears more than a passing resemblance to that of a horse. Or the group of Flat-fish, or Sole, which are active and typically fish-shaped when young, but gradually become flattened, not dorso-ventrally as in the Skates, but laterally so that they lie on one side instead of on the ventral surface. (W. fs. 72, 73.)

An example of dorso-ventral flattening in a Teleost is found in the large, sluggish Goose-fish (*Lophius piscatorius*) — one of the most bizarre and almost repulsive looking species of fish to

be found. It lies, as a rule, inactively on the bottom and attracts other animals into its enormous mouth by means of a long, waving dorsal fin ray. Another highly modified, bizarre Teleost is the Porcupine-fish, which is a rather sluggish, bottom-living type. At times, when disturbed, they are able to inflate themselves with the inhaled air so that they become almost globular in shape. Tropical fishes, as found, for example, in the coral reefs (page 53), and also many deep sea fish present an extraordinary array of coloring and adaptations to their particular life conditions. (W. f. 74.)

CLASS IV. AMPHIBIA. This vertebrate class includes the Caudata, such, for example, as *Necturus* and *Amblystoma*, shown in figure 10; all of which are tailed forms. They are for the most part aquatic and, in some cases, the gills are functional throughout life. Most species, however, undergo metamorphosis, the gills cease to function, and air-breathing lungs develop. The Salientia, such, for example, as the Frogs and Toads, are all tailless forms when fully mature. In the larval, or tadpole, stage they are aquatic, tailed, fish-like organisms with functional gills and no limbs. Then they metamorphose into air-breathing, adult individuals which are markedly different from the tadpole in various ways, but particularly in the absence of the tail and the presence of two well-developed pairs of pentadactyl limbs. (W. fs. 76-78.)

Thus the Amphibia are aquatic or semi-aquatic animals which breathe by gills at all times or, more often, only during the larval period. With very few exceptions the amphibian skin is smooth and shows no exoskeletal structures, such as the scales of fishes or of reptiles. Even more noteworthy are the pentadactyl limbs, which mark a wide advance over the fish fin, and the development of lungs. Inasmuch as the Frog is used later as a basis for the description of, and laboratory studies on, the vertebrate organism, it will not be necessary to consider the Amphibia further at this point.

CLASS V. REPTILIA. In this class, we encounter for the first time a group of vertebrate animals which are air-breathing at all stages in their life history. The embryonic gills are never functional. The skin, in distinction to that of the Amphibia, is marked by a considerable development of exoskeletal structures such as are shown in the bony plates of the turtle or the scaly snake skin. Undoubtedly the Reptiles reached their greatest development in

prehistoric periods when the living representatives included the enormous land-living Dinosaurs, such as *Brontosaurus*, shown on page 177, the aquatic *Ichthyosaurs*, also of great size, and the *Pterosaurs* with the fore limbs modified for air flight and showing other structural features which are believed to mark them as a connecting link with the true birds. (W. f. 79.)

Three important orders of living Reptiles are recognized, namely, (1) the *Testudinata*, which includes the Turtles and Tortoises; (2) the *Crocodylina*, which includes the Alligators and Crocodiles; (3) the *Squamata*, represented by Snakes, Chameleons, and Lizards.

The Turtles and Tortoises possess a comparatively short body which, in all species, is almost completely enclosed in a hard, box-like exoskeletal shell. No other Vertebrates possess such a structure. This group is very largely aquatic in habitat and ranges in size from a few inches in length and weighing a few ounces to four or five feet and weighing some 500 pounds. (W. f. 80.)

The Crocodiles are large aquatic Reptiles with an elongated body ending anteriorly in a long snout with a pair of nostrils at the tip. The tail is long and very muscular. The skin is unusually heavy and almost completely covered with horny exoskeletal plates. The limbs are well-developed and more or less web may be present between the digits of the hind limbs, but they are not well-adapted for locomotion on land. The eyes protrude above the dorsal surface so that they lie above the surface of the water when the animal is floating. The Crocodiles and Alligators belong to the same family, and show few differentiating features. Thus in the Alligator the snout is broader and less pointed, the body heavier, and their disposition more favorable to strangers!

The *Squamata* are almost entirely terrestrial animals, and the limbs, when present, are well-adapted for locomotion on land. The Chameleons and the Lizards, with few exceptions, possess two pairs of pentadactyl limbs. In the Chameleons, the digits are grouped to permit grasping of objects, such as tree branches. In the Snakes, no limbs are present, but inasmuch as internal vestigial remains of limbs and limb girdles are to be found in various species, it is concluded that they have descended from limbed types. The body is enclosed in a scaly, exoskeletal covering which is shed periodically, and then formed anew as a secretion by the underlying dermal cells. (W. fs. 81-83, 230.)

CLASS VI. AVES. Since the Aves, or Birds, are the only animals which possess feathers, this one character serves to differentiate them from all other groups. The main portion of a feather develops in the dermis of the skin, and is covered externally by an epidermal layer. They are closely related to the reptilian scale. Birds possess two pairs of limbs, but the fore limbs are highly modified for flying. Even the most primitive fossil birds show this amazing fore limb development, and it persists throughout all species. (W. fs. 84-86, 233.)

Another interesting and important feature found in this class is the maintenance of a uniform body temperature (homothermal or, commonly, warm-blooded), a condition which is found in only one other group of animals, namely, the Mammals, in which Man is included. In all other classes of Vertebrates and Invertebrates, the body temperature varies with the environment of the animal (poikilothermal, or, commonly, cold-blooded). Attention should also be called to the fact that all Birds and Mammals possess a four-chambered heart. This condition is found in certain Reptiles, but it is not universal in that class. Although teeth can be demonstrated in certain fossil birds, they are lacking in present-day species.

The Birds represent an extremely homogeneous group, so much so that it is very difficult to find a sufficient number of differentiating structural characters to construct a satisfactory scheme of classification for the nearly 20,000 species which are known. Excluding fossil forms, seventeen orders are usually recognized, and the basis of classification depends, for example, upon such relatively minor structural features as the character of the feet and beaks. (W. f. 85.)

CLASS VII. MAMMALIA. This large, interesting, and most important class of Vertebrates is characterized by the development of hair in the skin. Abundant in many species, where it forms a heavy external covering, in certain other types it may be considerably restricted or in an extreme case, such as in certain Whales, be entirely lacking. Another mammalian characteristic is to be noted in the mammary glands, present on the ventral surface of the female, which form a secretion (milk) for nourishing the young after birth. A constant body temperature is maintained by all Mammals.

Probably the greatest amount of external variation is to be

found in the structure of the limbs. These may vary from two pairs of nearly typical pentadactyl limbs, as in Man, to the condition found in the Whale, where the fore limbs are paddle-shaped structures, although maintaining the fundamental pentadactyl arrangement, and the hind limbs are entirely lacking. Or again a reduction of digits may occur, as in the Horse, where only the third digit of each limb is functional. In fact a very complete series of limbs of the various Mammals can be arranged to show the ADAPTIVE RADIATION from a basic, or generalized, type to the highly specialized types in conformity to the chosen environmental conditions. (W. fs. 201-207.)

Again, the mammalian exoskeletal structures show great variation and are used in classifying this group. Thus we have Mammals with claws, or UNGUICULATA (*e.g.*, Bat, Dog, Bear, Rabbit, Squirrel, etc.); Mammals with hoofs, or UNGULATA (*e.g.*, Horse, Cow, Pig, Elephant, etc.); Mammals with nails (*e.g.*, Monkey, Ape, Man, etc.). Mammalian teeth are also a valuable aid in classifying the group.

In all Mammals, except a few of the most primitive species, the fertilized egg is retained in the body of the mother for early development. It is interesting to note that, in the primitive mammalian types, large-yolked eggs are laid which are very similar to those of Reptiles and Birds.

The Mammalia are commonly divided into three subclasses, namely, the PROTOTHERIA, the METATHERIA, and the EUTHERIA. The Prototheria are egg-laying Mammals. There are only a few species known (*e.g.*, *Ornithorhynchus* (Duck-bill) and *Echidna* (Spiny Ant-eater)) and these are very closely restricted in their distribution. The Metatheria are the pouched Mammals, or Marsupials. The young are born in a very immature condition, and are carried by the mother, for a time, in a special pouch, or MARSUPIUM, present on the ventral surface of the female. This is also a very small subclass with the Kangaroo and, in this country, the Opossum as typical examples. (W. fs. 87, 88.)

The Eutheria, in which the young, owing to the presence of the placenta in the female, are retained for a longer period of uterine growth and are born in a comparatively highly developed condition, include all the remaining mammalian types. These Placentals comprise the familiar species of domesticated animals as well as the Primates. The interest and importance which, therefore, attaches

to the Eutheria, justifies our further consideration of their classification. Considerable variation in the subdivisions of the Eutheria is found among the various systematists. For the present brief consideration, we may recognize nine orders which we shall arrange as follows :

Order 1. Insectivora. This order includes certain common species, such, for example, as the Mole, Hedgehog, and Shrew. *Gymnura* is an important genus. They are small, furry, terrestrial forms, with plantigrade, unguiculate appendages which are variously modified. They are largely insect eaters. (W. fs. 201, 205.)

Order 2. Edentata. Examples of this class are noted in the Armadillo, Ant-eater, and Sloth. Of these, the Armadillo is found in the United States, and it only in Southern Texas. Practically the only characters in common are the absence of the front teeth and the lack of enamel. (W. fs. 39, 204.)

Order 3. Chiroptera. The Bats, which constitute this order, are characterized by a modification of the fore limbs which adapt them for flight. The hind limbs are clawed and suited for grasping. (W. fs. 207, 227.)

Order 4. Rodentia. This is the largest order of Mammals in the number of species included. Also the number of individuals of certain species and the extent of their geographical distribution is extraordinary, as, for example, the House-mouse and the Gray-rat. The Rodents are characterized as the gnawing Mammals. They possess one or two pairs of long incisor teeth particularly adapted for this purpose. Their destructiveness together with the disease-carrying ability of certain species make them pests of the first order. All things considered, the Rat is probably the greatest animal pest with which we have to contend. Claws are present on the digits. Additional examples of Rodents are to be found in the Squirrel, Rabbit, Guinea Pig, Beaver, Gopher, Porcupine, etc. (W. fs. 108, 187.)

Order 5. Carnivora. Although the Carnivores are characterized as the flesh-eating Mammals and possess certain teeth, particularly the canines and premolars, which are adapted for tearing animal tissues, as well as heavily clawed digits, nevertheless species are known which subsist on both animal and vegetable food (omnivorous) or even on vegetable food alone (herbivorous). On the whole, they are fairly large animals with a heavy coat of

fur which is frequently of considerable commercial value. The Carnivora are clearly divided into the terrestrial forms, a few important examples of which may be noted in the Dog, Fox, Wolf, Cat, Lion, Tiger, Bear, Raccoon, Mink, Skunk, and into the aquatic types, such, for example, as the Seals, Sea-lion, and Walrus. The aquatic forms exhibit considerable structural adaptation for their water life, including completely webbed digits.

Order 6. Cetacea. This is a rather small order of exclusively marine animals, and includes the Whale, Porpoise, and Dolphin. They are tremendously modified for their mode of life, probably more so than any other order of Mammals. The teeth are restricted to one jaw or lacking entirely in the adult, as is also the hairy covering. No hind limbs are present. The largest living animal, the Sulfur-bottom Whale (*Sibbaldus sulfurous*), may reach a length of nearly a hundred feet and a weight of close to 300,000 pounds. (W. fs. 90, 206.)

Order 7. Sirenia. A small and relatively unimportant order of aquatic Mammals, including the Manatee and Dugong. Only seven species are known, three of which are found along the Atlantic coast. The Florida Manatee (*Manatus americanus*) is the best known. The order is characterized by the fin-like fore limbs, the absence of hind limbs, and the peculiar horizontal tail fin. (W. f. 91.)

Order 8. Ungulata. Among the Ungulates, Man has for ages found some of his most important animal allies, including such almost indispensable species as Horses, Cattle, Sheep, Hogs, and Camels. These species he has long since domesticated to provide a constant supply of animal food, materials for clothing, and transportation. We can characterize the Ungulata as the hoofed mammals, and they may be divided into the even-toed and odd-toed types. Thus the Cow, Pig, and Camel may be given as examples of the even-toed Ungulates, while the Horse, Rhinoceros, and Elephant are examples of the odd-toed. The modification of the pentadactyl limb probably reaches a climax in the monodactyl appendage of the Horse. Other noteworthy structural features of certain Ungulates include the peculiar stomach of the Ruminants which permits a regurgitation of food for further mastication; the very large antlers of the Moose and Deer, which are shed annually; the horns which develop on certain head bones of the Rhinoceros; and the tremendous trunk, or

proboscis, of the Elephant, as well as the tusks which are modified, greatly enlarged incisor teeth. Among the outstanding structural features of economic importance are the character of the flesh of certain species which makes it desirable for human consumption; the character of the skin (as in Cattle) which makes it suitable to tan for leather; and, finally, the development of mammary glands which provide a supply of milk — an almost indispensable article of human food which is the basis of the very important dairy industry. (W. f. 92.)

Order 9. Primates. This final order of Mammals, to which Man belongs, is primarily characterized by the great development of the brain — a feature generally regarded as being of sufficient importance to make it necessary to place this group as the highest order of the Mammals, even though in certain other features, such as the development of the muscular tissue, character of teeth, and condition of young at birth, the species included are less advanced than certain other orders, particularly the Ungulates. Other primate features are noted in the digits of the hand and foot, which bear nails rather than claws or hoofs, and also in that the first digits (toe or thumb) are opposable (one or both) to the other digits. The primate appendages are primarily adapted for grasping, a function which corresponds to the arboreal habitat of the great majority of species.

The Primates are divided into two suborders on the basis of a comparatively minor structural feature, namely, the separation or contact of the front teeth in the anterior median line. Thus in the suborder *Lemuroidea* the teeth are separated, while in the suborder *Anthropoidea* the teeth are in contact. The Lemurs and Marmosets, which belong to the *Lemuroidea*, are rather small-sized quadrupeds with a comparatively long tail. The long-nosed lemur face is not unlike that found in certain of the lower Mammals. The Marmosets are climbers, and it is interesting to note that there are claws on certain digits. (W. f. 93.)

The *Anthropoidea* includes all the remaining Primates, such as the long-tailed Monkeys of which there are numerous species found in South America and various regions in the Old World; and the short-tailed Anthropoid Apes, represented by the Gibbon, Orangutan, Chimpanzee, and the rare Gorilla. Finally, Man is classified as a separate family (*Hominidae*) of the *Anthropoidea*. Only one species (*Homo sapiens*) is recognized at present. The Anthro-

poid Apes are regarded as the closest structurally to Man. This is based on such features as the absence of a tail, the frequent occurrence of bipedal locomotion, the very high degree of intelligence, and the almost human facial structure and expression due to the enlarged cranial bones and reduced facial bones.

In Man, the bipedal locomotion is universal, the big toes are not opposable, the formation of hair is not so abundant, but, above all, the tremendous development in the size and quality of the fore-brain has given Man a mental superiority which far transcends that of any other living organism. His mental equipment has enabled him to overcome greatly varying conditions of climate, so that his distribution is world-wide, as well as to dominate other types of life to a high degree.

Although only one species of mankind is believed to be represented on the Earth today, at least three groups, or races, are to be noted, namely, the Negroid, the Mongolian, and the Caucasian. The character of the hair, the shape of the nose, the color of the skin, and other minor structural characteristics serve as identifying features.

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THE FROG

Having considered the characteristic features of the Vertebrates and their classification in so far as is necessary for our present discussion, we are now in a position to proceed with a detailed description of the structure and life processes of a representative Vertebrate. Because of its availability, convenient size, and general adaptability to laboratory work, we shall select the FROG as the type animal, but an endeavor will be made to consider the various features from the comparative standpoint, particularly with reference to the condition found in the Mammals.

A. EXTERNAL STRUCTURE

The body of the Frog is divided into two regions, the HEAD and TRUNK. The NECK region, which is typically present in the higher Vertebrates and permits a wide variety of head movements independently of the rest of the body, is entirely lacking. (W. f. 78.)

A study of the external features of the Frog's head reveals at once the very large mouth with upper and lower jaws; the latter also present on all of the Vertebrates except the Cyclostomes. The upper jaw has a projecting, fleshy upper lip with a ventral groove into which the lower jaw fits very perfectly so as to form an airtight joint which, as will be shown later, is a necessary feature of breathing in the Frog. A pair of dorsally placed eyes with upper and lower lids is another prominent feature. Normally they project a considerable distance above the surface. They can, however, be drawn back into the eye sockets, or orbits, of the skull and entirely covered over by the lower lids; the upper lids being almost immovable in this animal. A slight excrescence in the skin, just anterior to a line drawn between the eyes, marks the BROW SPOT which is connected with the brain at an early stage of development. It is believed to represent the remains of a so-called pineal eye, which at present is known to be functional only in one species (*Sphenodon punctatum*) which belongs to the Reptiles. Also on the dorsal surface and near the anterior end of the head is a pair of small openings, the EXTERNAL NARES, which open into the mouth cavity and function in connection with the olfactory and respiratory structures, in essentially the same manner as the nostrils in the nose of Man or other higher forms. Posterior

to the eyes, a pair of large, circular TYMPANIC MEMBRANES are conspicuous; one on each side of the head. These are membranous, disc-like structures embedded in the skin which function as a part of the auditory apparatus, or ear. They are, in fact, EAR DRUMS, essentially the same as in Man, but lying on the surface.

Attached to the trunk are two pairs of jointed pentadactyl limbs which are adapted both for aquatic and terrestrial life. These appendages represent a tremendous modification of, and advance over, the paired fish fin, and the various constituent structures are homologous with those in the limbs of the higher classes of Vertebrates.

The fore limb is composed of three main parts, commonly known as the UPPER ARM, FOREARM, and HAND. The latter is composed of the wrist and four well-formed digits, together with a very rudimentary first digit, corresponding to our thumb, which can be felt through the skin. The hind limb has the same general structure as the fore limb, but is much larger and more powerful. The various parts of it are commonly spoken of as the THIGH, SHANK, and FOOT. The latter is composed of the ankle and five complete digits. Between the digits an INTERDIGITAL WEB is developed. A more detailed description of the bones of the limbs and also of the general skeletal structure will be given later.

The outer covering of the Frog's body consists of a smooth slimy skin which is heavily pigmented, particularly on the dorsal surface of the body. The skin of the Frog and of other Vertebrates is a very important structure. It is far more than a mere external covering. In general, it may be said to have four important functions, namely, support, protection, respiration, and secretion. In connection with the function of support, it is apparent that the skin is essentially a heavy, resistant covering enclosing the various body tissues.

The skin functions beautifully as a protection against unfavorable environmental features. In the first place there are very few disease germs that can penetrate the unbroken skin. Also the skin is the tissue in which the various protective exoskeletal features are formed, such as the scales of Fishes and Reptiles, the feathers of Birds, the hair of Mammals, as well as claws, nails, and hoofs. The Frog's skin entirely lacks these hard exoskeletal structures, but they are of general occurrence in most Vertebrates. Another feature which is well-shown in the skin is PROTECTIVE

COLORATION ; the ability to change the color scheme so as to blend as closely as possible with the surroundings — an animal camouflage, as it were. In the Frog, color changes take place by the expansion and contraction of specialized pigment cells, or CHROMATOPHORES, which lie just below the surface.

The wet, mucus-covered skin of the Frog undoubtedly plays a large rôle in the respiratory activities. It is plentifully supplied with blood vessels, and the interchange of carbon dioxide and oxygen through the skin is a continuous process. The small poorly-developed lungs of the Frog are not able to handle the entire respiratory exchange, and the animal will die finally if the exchange through the skin is entirely stopped, as happens when it remains dry for a prolonged period.

Finally, in the Frog, and other types, the skin is abundantly supplied with secreting structures, or GLANDS. Two varieties, the MUCUS and the POISON GLANDS, are usually found. The mucus glands continually secrete a slimy material which covers the skin and protects against drying when the Frog is out of water. The secretion of the poison glands is known to be of a poisonous nature and is undoubtedly protective.

B. THE BODY TISSUES

Before proceeding to a description of the various organ systems of the Vertebrate, attention should be called to the EPITHELIAL, MUSCULAR, and SUPPORTING tissues which, together with the NERVOUS and VASCULAR elements, are almost everywhere present in all the organs of the body. Thus, to take a single example, the alimentary tract — in addition to the all-important mucosa cells which actually carry on the essential functions of digestion and absorption — contains epithelial, muscular, connective, vascular, and nervous tissues. Organs, then, are composed of a variety of tissues. Consideration is given to the vascular and nervous tissues in later sections, so we may now give attention to the epithelial, muscular, and supporting elements. (W. pp. 132-145.)

1. *Epithelial Tissue*

Epithelial cells cover the exposed surfaces of the body structures both externally and internally. Thus the outermost portion of the skin, which is in contact with the environment, is covered with several layers of epithelial cells, the most external of which are exceedingly thin, flattened cells (SQUAMOUS EPITHELIUM) which

are in close contact with each other to form a tile-like surface. The cells of the succeeding under layers of skin epithelium gradually become thicker and appear like tiny cubes — hence the term CUBOIDAL EPITHELIUM. Finally, the COLUMNAR EPITHELIUM is reached in which the individual cells are more or less tubular in shape. Epithelium, as in the skin, consisting of several layers in which a gradual variation in shape is noted, is spoken of as STRATIFIED EPITHELIUM, and may be found in various regions. Inside the body we find that the abdominal cavity is lined by peritoneal epithelium. Again the alimentary tract is covered both outside and inside with epithelium. The inside lining of the alimentary tract is derived from the endoderm, and it is these cells which function in digestion and absorption. (W. f. 32, A.)

Another important type of epithelium is known as CILIATED EPITHELIUM, and, as the term indicates, cilia are present on the cells. This type of ciliated epithelial cell is found in the lining of various tubes and ducts where, by the coördinated movements of the cilia, they cause the movement of fluids and other materials. Examples of ciliated epithelium in the Frog may be found in the roof of the mouth and throat, in the kidneys, and in the oviducts.

Many types of glands which manufacture and secrete important substances are formed from epithelial cells so that we may speak of the GLANDULAR EPITHELIUM. Such glands may be unicellular (GOBLET-CELL), as found in the epithelium lining various regions of the alimentary canal, which synthesize and secrete the essential digestive enzymes. Or multicellular glands of many different varieties are present, such as was noted above in the case of the mucus and poison glands in frog skin. In the human skin abundant SWEAT GLANDS are present and also the SEBACEOUS GLANDS, at the root of each hair, which secrete an oily substance. In the mammalian female, the large, paired mammary glands which secrete an abundant supply of milk to nourish the newly born offspring are, of course, very important. In certain domesticated Ungulates, notably the goat and cow, these glands are particularly large and highly developed, and the milk secreted, since it is well-suited for human consumption, forms the basis of the world-wide dairy industry. (W. fs. 33. 34. 96.)

Finally, the surface epithelial cells are, in numerous instances, modified for peripheral sense organs in association with the nervous system. Thus we may speak of SENSORY, or NERVOUS, EPITHE-

LIUM. Examples of this are found generally distributed in the skin epithelium covering the body. In Man, sensitive epithelial cells respond to cold, heat, pressure, etc. The sense of taste in the tongue and the amazingly keen olfactory sense found in many Vertebrates are due to sensory epithelial cells. (W. f. 146.)

2. Muscular Tissue

The specialized contractile MUSCLE TISSUE which, responding to the control of the nervous system, brings about through its own contractions the almost innumerable and continuous movements present in higher animals, is necessarily very widely distributed. Muscle tissue may be classified as (a) the UNSTRIATED, or INVOLUNTARY, muscle tissue which is not under direct control of the will, and (b) the STRIATED, or VOLUNTARY, muscle tissue, the movements of which are under voluntary control. The unstriated muscle tissue, examples of which may be found in the various organs, is under the general control of the autonomic nervous system. (c) CARDIAC muscle tissue in the heart is also involuntary in its functioning but structurally is regarded as a separate type of muscle tissue. (W. fs. 98; 99.)

The unstriated muscle tissue which for the most part forms the muscular layers in the walls of a number of the important organs, such as those of the alimentary canal, blood vessels, and urinary bladder, is regarded as a simpler type than the striated. A microscopic examination shows that it consists of elongated, spindle-shaped cells, each with a nucleus which is also elongated in the same direction as the cell. The muscle cells are frequently branched at the ends. Also there is a considerable variation in their length. For example, in the walls of the blood vessels the cells are short and correspondingly thick, whereas in the walls of the bladder they are long and thin. The cytoplasm shows a fine longitudinal striation which is very different from the marked, transverse striations of the voluntary type of muscle tissue. The spindle-shaped cells lie close together with a certain amount of cement substance and connective tissue elements intermingled. Thus they are closely held together and work as a unit. The rate of contraction in unstriated muscle tissue is much slower than that of striated muscle tissue, but the movements can be continued for a longer time. (W. fs. 7, B; 34.)

The striated muscle tissue of the body is largely centered in the

muscles of the body wall and of the appendages. It is separated into definite units, the muscles proper. For example, in the hind limb of the Frog there are some eighteen separate and distinct muscles which bring about the various movements of the leg. All these muscles are attached to the bones by means of specialized connective tissue elements known as **TENDONS**. In general, one end of a muscle, known as the **ORIGIN**, is attached to an immovable bony structure, while the opposite end, known as the **INSERTION**, is attached to a movable bony structure. The **GASTROCNEMIUS MUSCLE**, which is a large muscle in the calf of the leg, may be taken as an illustration of the origin and insertion of a muscle. It has a double origin in, first, a tendon at the end of the thigh bone (**FEMUR**) just above the knee joint, and second, in a tendon attached to another tendon from the triceps muscle higher up the leg. These points of origin are relatively immovable. The insertion of this muscle is in various foot bones. When it contracts it causes an extension of the foot and also a flexing movement of the leg at the knee joint. (W. f. 98.)

A muscle that produces an extension, such as just noted in the foot, is known as an **EXTENSOR**; one that causes a flexion of the part is known as a **FLEXOR**. The gastrocnemius muscle produces both these movements. There are a number of other types of muscles classified according to the movement which they produce. Among these are the **ADDUCTOR** muscles which draw the limb in a posterior direction toward the long axis of the body; the **ADDUCTOR** muscles which draw the limb in an anterior direction toward the long axis of the body; the **LEVATOR** muscles which raise some part of the body, such as the lower jaw, and the **DEPRESSOR** muscles which work in an opposite direction.

A microscopic examination of striated muscle tissue shows that it is always enclosed in a connective tissue sheath, known as the **PERIMYSIUM**, which contains blood vessels and nerves. The perimysium continues beyond the end of a muscle as a tendon which is usually attached to a bone. Sheets from the perimysium radiate throughout the body of each muscle and separate it into a number of muscle bundles, termed **FASCICULI**. Each fasciculus contains a great many individual muscle fibers which are, in turn, separated from each other by a further continuation of the perimysium, known as the **ENDOMYSIUM**.

The muscle fibers, microscopic in size, and enclosed by a delicate

membrane, the SARCOLEMMMA, are the ultimate units of muscular structure, and every muscle contains a large number of such units. Distributed through each fiber are several elongated nuclei. It is believed that each fiber represents a greatly modified single cell in which the original nucleus has divided many times without a division of the cell body. The cytoplasm, or SARCOPLASM, of the striated fibers exhibits both a transverse and a longitudinal striation, the former being much the more prominent. The longitudinal striations are due to the presence of tiny, filamentous strands, the SARCOSTYLES, which extend longitudinally through each cell. These are supposed to be the contractile elements in the fiber. With a sufficiently high magnification, it is apparent that the transverse striation is due to the presence of alternate light and dark bands which run across the muscle. The muscle fibers are thus divided into segments, or SARCOMERES, which constitute the dark areas, and these are separated by light bands. When a muscle is contracted, the bands are more closely approximated than when the muscle is relaxed. (W. 32, *E.*)

The cardiac muscle tissue, which forms the walls of the heart, represents a distinct type which, however, shows certain morphological relations to the other two types. The cardiac tissue cells, while retaining their identity as do the cells in the unstriated muscle tissue, are attached to each other by strands of cytoplasm. On the other hand they have a definite transverse striation and in this respect resemble the striated muscle tissue.

CONTRACTION OF MUSCLE TISSUE. The question as to what causes muscle tissue to contract when the proper stimulus is received from the nervous system is one which is still unsolved although many theories have been proposed. In considering this problem, it is interesting to know that muscle tissue can contract when removed from the body of an animal. Contractility, therefore, is not dependent upon any connection with the body. As an example of this, the study of a 'muscle-nerve preparation' is of value. Such a preparation is made by removing a muscle from an anesthetized animal, say the large gastrocnemius muscle from the hind leg of a Frog. The dissection should be done in such a way as to leave the sciatic nerve, which innervates this region, attached to the muscle. The dissected muscle with the attached nerve can be kept wet with a normal salt solution. The use of such a solution prevents the tissues from drying, and when so treated they

can be kept alive for the experimental work for some hours. The muscle may next be attached to an immovable body at one end which represents the **ORIGIN**, and to a movable body at the other end, which represents the **INSERTION**. The nerve may now be stimulated in various ways, as, for example, by contact, electrical current, or chemical solutions. When the end of the nerve is stimulated a nerve impulse passes through it and into the muscle in the same way, apparently, as if it were normally situated in the body and the muscle received a stimulus from the central nervous system. Furthermore the result of this nerve impulse is the same, for the muscle immediately contracts, thereby causing a movement of the lever at its insertion.

The above experiment demonstrates that living muscle tissue will contract outside the body, and also that the nerve can be artificially stimulated to bring about the muscular contraction. The question as to what actually takes place under such circumstances in both the muscle and nerve tissue is largely unknown, although it has been the subject of a great deal of experimental work.

3. *Supporting and Connective Tissues*

These widely distributed tissues include a variety of different types, all having as their chief functions the support and protection of the various organs. They are divided into two types, the **EXOSKELETAL** and the **ENDOSKELETAL**.

The **EXOSKELETAL** structures are external, and they develop from both the inner and outer layers of the skin. In some Vertebrate animals, as for example the Turtle, the exoskeleton forms a protective covering over practically the entire body. In other groups of Vertebrates, the exoskeletal structures, while not forming a covering over the entire body, are present in the form of nails, hair, feathers, etc. In the Frog, all such exoskeletal structures are lacking in the skin.

The **ENDOSKELETAL** structures are internal and comprise the supporting and connective tissues, including bone which is regarded as the highest development of the endoskeleton. In general, all of this group of tissues contains a relatively large amount of ground substance, or **MATRIX**, which is intercellular in position; that is to say, this material lies outside the cell walls, between the cells. In some of the connective tissues the ground substance constitutes

the larger part of the tissue. It begins to develop very early in the Frog embryo as a homogeneous substance which later becomes modified in various ways to form the matrix of the different types of connective tissue and bone. For example, it may remain largely unchanged, as in some of the simpler types of connective tissue; it may become a dense fibrillar material, as in a tendon; or it may become largely infiltrated with certain inorganic salts, chiefly calcium carbonate, and form the basis of the hard bone tissue. (W. f. 32, *B, C, D.*)

WHITE FIBROUS TISSUE. There are several different kinds of connective tissues recognized. One type, which has a very wide distribution, is known as the **WHITE FIBROUS TISSUE**. This may be obtained from almost any region of the body; for example, in the skin, or surrounding the muscles and nerves, or forming the supporting framework in various organs, or as **TENDONS** attaching the muscles to the bones. When examined microscopically, the white fibrous tissue will be found to consist of a considerable proportion of ground substance in which are bundles of **COLLAGENOUS FIBERS** having a characteristic wavy appearance. The white fibrous tissue also contains a number of **ELASTIC FIBERS**, mentioned below. Scattered among the fibers and embedded in the ground substance are numerous connective tissue cells, known as **FIBROBLASTS**. These are elongated, spindle-shaped cells which have a tendency to stretch out along the fibers. (W. f. 32, *B.*)

ELASTIC TISSUE. Another type of connective tissue, which is known as **ELASTIC TISSUE**, consists of heavier, straight fibers which frequently branch. The elastic fibers are found in abundance in the walls of the blood vessels, and they also form certain ligaments. The nature of elastic tissue is such that when tension is applied it will stretch and then return to the original condition when the tension is released. This condition is very different from that present in the tendons of the body, which consist almost entirely of white fibers. A tendon lacks elasticity and will break under tension rather than stretch. Generally the white fibers and the elastic tissue are found to be more or less intermingled in the various connective tissues. For example, the ligaments contain a great deal of the elastic tissue and very few of the white fibers, while the reverse is true of the tendons. (W. f. 32, *B.*)

FATTY OR ADIPOSE TISSUE. This type of tissue is found more or less scattered throughout the body, and is generally regarded

as a type of connective tissue in which the cells have become somewhat enlarged and atypical in shape as a result of fat storage.

CARTILAGE is a highly developed connective tissue, which is always abundant in the Vertebrate embryo. In the lowest classes, it remains as the permanent skeleton, but in the higher types it is later replaced by true bone. Some of the cartilaginous material, however, remains unchanged throughout life. Cartilage is marked by the presence of an exceptionally large amount of transparent, intercellular ground substance which possesses great strength. The cartilage cells are embedded in this matrix in numerous cavities, known as **LACUNAE**, each of which may contain one, two, or even more cells. There are various kinds of cartilage, depending upon the character of the ground substance. In **HYALINE CARTILAGE** the ground substance is homogeneous, but in the mixed and fibrous types of cartilage the ground substance shows a marked fibrillar nature due to the presence of either white or elastic fibers or both. Hyaline cartilage is the more common type, and it is found in the joints, in the breast bone, between the vertebrae, and in a number of other places in the body. (W. fs. 32, C; 100.)

BONE. The greater portion of the bone tissue of the body, as has been noted, is first formed as cartilage. Such bones are, therefore, known as **CARTILAGE BONES** in distinction to a less frequent type, known as **MEMBRANE BONES**, in which the cartilage stage is lacking, and the bone tissue develops by an ossification of soft membranes. The general structure of mature bone shows a resemblance to cartilage in that the bone cells, or **OSTEOBLASTS**, are embedded in cavities in the matrix in somewhat the same way as in cartilage. The microscopic structure of bone can be seen to good advantage in a properly prepared transverse section through one of the leg bones, for example, the femur. Such a section shows that the bone is not a solid rod throughout, but consists of an outer cylinder of bone tissue enclosing an internal cavity which runs the length of the bone. In life, the cavity is filled with a soft, highly vascularized tissue, the **BONE MARROW**. The bone tissue is covered on the outside by a living connective tissue sheath, the **PERIOSTEUM**, and is "arranged in concentric layers, or **LAMELLAE**, which contain numerous lacunae in which lie the **BONE CELLS**. From the lacunae, fine branching tubes, or **CANALICULI**, containing processes from the bone cells, are given off which extend in all directions and anastomose with the canaliculi of neighboring

spaces." The osteoblasts lying next to the periosteum continue to add new bone during development so that the bone increases in diameter by the addition of outside layers. The bone tissue may also increase to a certain extent by the addition of bony tissue in the marrow cavity. (W. f. 32, D; 100.)

4. *Skeleton*

The living bony endoskeleton of a Vertebrate may be divided into (i) the AXIAL SKELETON consisting of the SKULL and VERTEBRAL COLUMN, and (ii) the APPENDICULAR SKELETON consisting of the LIMBS and the LIMB GIRDLES. (W. pp. 138-144.)

I. AXIAL SKELETON

A. The Skull. The Vertebrate skull consists of two portions: the CRANIUM, which is the brain case, and the underlying FACIAL PORTION. Making up the skull is a considerable number of bones as well as certain permanently cartilaginous elements. The cranium in the Frog is small, narrow, and elongated in the direction of the long axis of the body. It encloses and protects the brain, together with the auditory and olfactory sense organs. At the posterior end of the cranium there is a large opening, the FORAMEN MAGNUM, through which the spinal cord leaves the cranium and passes into the vertebral column. Surrounding the foramen magnum are the EXOCCIPITAL bones, each of which bears a rounded prominence, or OCCIPITAL CONDYLE, which articulates with the first vertebra and thus forms the connection between the skull and the vertebral column. Just anterior and lateral to each exoccipital bone is a PROÖTIC bone. Lying in the anterior portion of the cranium and also forming the posterior wall of the nasal cavity is an unpaired bone known as the SPHENETHMOID. The five bones just noted; that is, a pair of occipitals, a pair of proötics, and the unpaired sphenethmoid, constitute the cartilage bones of the Frog's cranium. (W. f. 103.)

There are also a number of membrane bones which form the dorsal covering of the cranium. There is a pair of long, narrow bones, the FRONTAL-PARIETALS, which result from a fusion of two pairs of bones, as commonly found in Vertebrates, namely, the FRONTALS and PARIETALS. The frontal-parietal bones connect posteriorly with the proötics and the exoccipitals, anteriorly with the sphenethmoid, and form the greater portion of the dorsal wall

of the cranium. A pair of small irregular bones, the **NASALS**, form the dorsal wall of the olfactory capsules. On the ventral surface of the olfactory capsules is a pair of small bones, the **VOMERS**, which bear the vomerine teeth. The ventral wall of the cranium is chiefly formed from a large unpaired, T-shaped bone, the **PARASPHENOID**, the long stem of which extends anteriorly, and the transverse portion posteriorly and to the sides, under each of the auditory capsules. (W. f. 103.)

The **FACIAL PORTION** of the skull consists of the upper and the lower jaws and the hyoid cartilage which with its bony processes forms a plate-like structure in the ventral wall of the mouth cavity where it supports the tongue. The **HYOID APPARATUS** in the Frog is not so complete as it is in the Fishes where it forms the elaborate gill-bearing visceral skeleton. (W. f. 103.)

The bones of the upper jaw are immovably fastened to the cranium. They consist of a pair of **PREMAXILLAE** bones which form the extreme anterior portion of the upper jaw, a pair of **MAXILLAE** which are posterior to the premaxillae and form the sides of the upper jaw, and a pair of **QUADRATOJUGALS** which constitute the posterior portion of the upper jaw.

Each side of the lower jaw has as its basis a cartilaginous rod, known as **MECKEL'S CARTILAGE**. Anteriorly each rod is largely covered by a **DENTARY** bone, and posteriorly by an **ANGULOSPLENIAL** bone. The jaws are attached to the cranium by a rather complicated suspensory apparatus consisting of three bones on each side, namely, the **SQUAMOSAL**, **PTERYGOID**, and **PALATINE**. (W. f. 103.)

The Mammalian skull is considerably modified from that just noted in the Frog. In the first place, the increase in the size of the brain has necessitated an increase in size of the cranium as compared with the facial region. This condition is seen in the most marked degree in the skull of Man, as may be shown by a comparison of the cranial and facial portions of the skulls of Man and the Gorilla. (W. f. 228.)

There is also a great tendency toward a complete fusion of certain bones so that the adult skull comprises a smaller number of separate bones than that of the embryo. Thus in early adult life there are twenty-two bones in the human skull. This number is considerably less than it was in earlier years and will be even more reduced in old age. (W. f. 105.)

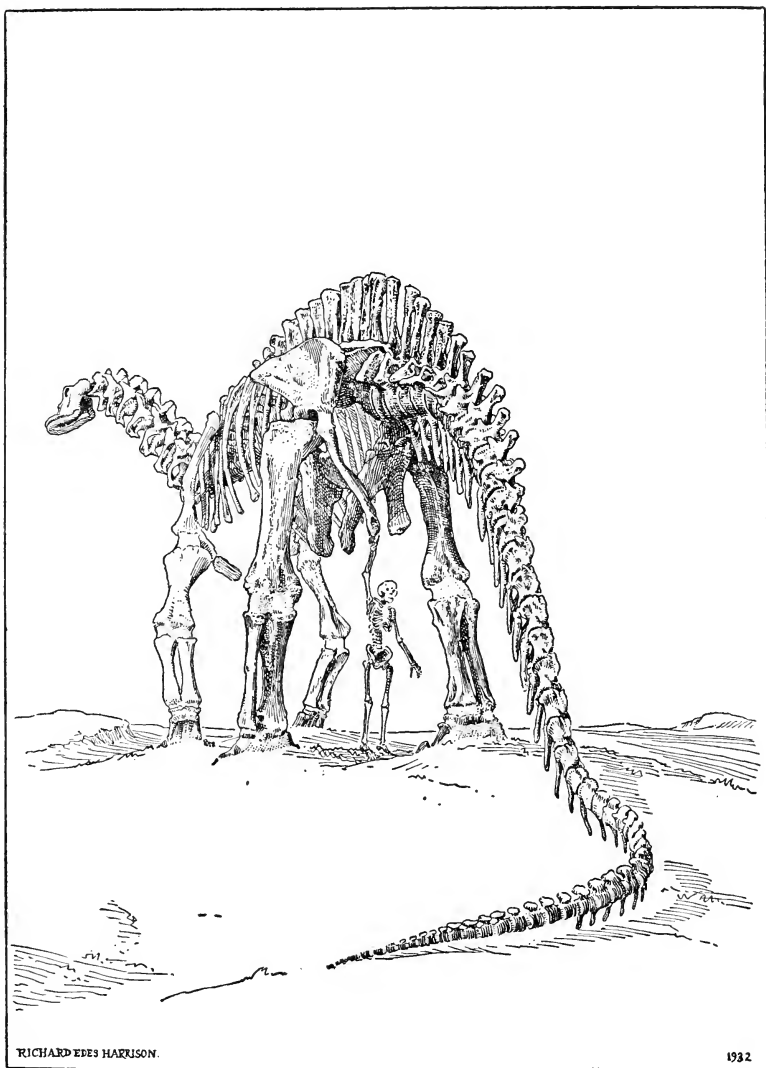


FIGURE 11

The bony skeleton of the Vertebrate reached its most massive development in the extinct reptilian Dinosaurs. The skeleton shown in this figure is from the largest known species, the giant *Brontosaurus excelsus*. The specimen was collected at Como Bluff, Wyoming, in 1881 and has just recently been mounted, as shown, in Peabody Museum, Yale University. It measures 67 feet in length and is 16 feet high over the hips. The weight of the animal is estimated at about 40 tons. For comparison of relative size, a full sized human skeleton is shown. Reference should be made to Lull's "Organic Evolution" (Macmillan) for complete description.

Teeth. The teeth of all Vertebrates are regarded as homologous structures which in their evolutionary history are related to the placoid scales of certain Fishes. They are composed of a thin, outer covering of ENAMEL, which forms from the epithelium lining the mouth, and DENTINE, which develops from the underlying mesodermal tissue. The latter constitutes the bulk of a tooth. Teeth in the various Vertebrate groups are subject to very great variation in number, shape, and function. In certain of the higher Vertebrates, including Man, the teeth are placed in deep pits, or ALVEOLI, in the jawbones. The portion of the tooth within an alveolus is known as the ROOT, while the exposed enamel-covered portion is termed the CROWN. We recognize four types of teeth in the higher forms, which, beginning anteriorly, are known as the INCISORS, CANINES, PREMOLARS, and MOLARS. (W. f. 104.)

In Man and most of the Mammals, two sets of teeth are formed. The first set in Man, the MILK TEETH, are replaced in the early years of childhood by the PERMANENT TEETH which develop in the jaws below the first set. The number of milk teeth varies somewhat, with a normal of 20, while in the permanent set there are 32 teeth, divided so that each half of each jaw contains 2 incisors, 1 canine, 2 premolars, and 3 molars. In order to state concisely the number of teeth in an animal a DENTAL FORMULA is made use of in which the letters *i*, *c*, *p*, and *m* indicate the incisors, canines, premolars, and molars respectively, and the numbers of each kind in *half* of the upper and lower jaws are shown by figures above and below a line. Thus the dental formula of Man is indicated as $i \frac{2}{2}, c \frac{1}{1}, p \frac{2}{2}, m \frac{3}{3} = 32$.

B. Vertebral Column. The vertebral column of the Frog is very short. It consists of nine typical vertebrae, together with a narrow, rod-like, unsegmented posterior extension, known as the UROSTYLE. Each vertebra consists of a solid oval portion, the CENTRUM, the center of which occupies the original position of the notochord ventral to the spinal cord. Dorsally and laterally on each centrum a bony structure, known as the NEURAL ARCH, is developed around the spinal cord. The space between the neural arch and the centrum in each vertebra constitutes the NEURAL CANAL in which the spinal cord lies. Each neural arch has a dorsal projection, the NEURAL SPINE, and, except in the first vertebra, a lateral projection on each side, the TRANSVERSE PROCESS, to which the muscles are attached. (W. fs. 101; 103.)

The vertebrae composing the vertebral column articulate with each other by means of ARTICULATING PROCESSES, or ZYGAPOPHYSES, which are developed both anteriorly and posteriorly on the neural arches. The anterior pair of processes of each vertebra, except the first, articulates with the posterior pair of the vertebra just anterior. Thus the vertebral column is made up of a series of definite articulating units, the vertebrae, each of which, by means of the neural arch, contributes a portion of the common neural canal containing the spinal cord. The vertebral column, while giving firm axial support, also permits a considerable amount of bending. The first vertebra possesses two concave articulating surfaces into which the convex prominences of the occipital condyles at the posterior end of the skull fit.

The structure of the vertebral column in the various Vertebrates is essentially the same as that just described for the Frog, but the number of vertebrae present is subject to considerable variation. In the Mammals, including Man, five regions are typically present, which, beginning at the anterior end, are known as the CERVICAL (neck region), THORACIC (chest region), LUMBAR (abdominal region), SACRAL (pelvic region), and CAUDAL (tail region). In the adult condition of Man there are 26 vertebrae in the vertebral column divided as follows: 7 cervical, 12 thoracic with a pair of ribs attached to each, 5 lumbar, 1 sacral, and 1 caudal. In early life there are 33 vertebrae present. The reduction is due to a fusion of 5 sacral vertebrae to form the SACRUM of the adult, and a fusion of the 4 caudal vertebrae to form the COCCYX. In most Mammals, except Man and the Anthropoid Apes, the number of caudal vertebrae is quite large, thus in the Cat there are 22 caudal vertebrae. (W. fs. 104-108.)

II. APPENDICULAR SKELETON

The appendicular skeleton of the Vertebrate, as typically found, consists of the FORE LIMBS and the HIND LIMBS, both of which are of the five-fingered, or PENTADACTYL TYPE, and the GIRDLES by which they are connected with the axial skeleton. The fore limbs are attached and supported by the shoulder, or PECTORAL GIRDLE, and by the breast bone, or STERNUM. The latter is the common ventral uniting structure for the two halves of the girdle, and also serves as a protection for various internal organs which lie in that part of the body. Each half of the PECTORAL GIRDLE is made up

of a number of bones and cartilaginous elements; the principal bones being the **SCAPULA**, **CLAVICLE**, and **CORACOID**. The scapula and coracoid on each side form a cavity, the **GLENOID FOSSA**, into which the proximal end of the **HUMERUS** of the fore limb fits. (W. f. 102, A.)

The **PELVIC GIRDLE**, which forms the support and attachment of the hind limbs, consists of a right and left half, each formed from three bones, the **ILIUM**, **ISCHIUM**, and **PUBIS**, the first being the largest. The ilium in the Frog connects anteriorly with the transverse process of the ninth vertebra, continues posteriorly nearly parallel with the median urostyle at the posterior end of the vertebral column, and, finally, connects with the ischium and the pubis. The ischium and pubis together with the posterior end of the ilium, form a common cavity, the **ACETABULUM**, into which the proximal end of the femur of the hind limb fits. (W. f. 102, B.)

Each **FORE LIMB** consists, first, of a large bone, the **HUMERUS** which, as mentioned above, articulates at its proximal end with the glenoid fossa of the pectoral girdle. The distal end of the humerus articulates with the **RADIO-ULNA**. This is a single fused bone in the Frog, but in many of the Vertebrates it consists of two separate bones, the **RADIUS** and **ULNA**. In the Frog there are six wrist bones (**CARPALS**), three of which articulate with the radio-ulna, and three of which articulate with the bones of the hand. Each of the five digits of the hand begins proximally with a **METACARPAL** bone. In digit I, there is no other bone. In digits II and III, the metacarpals are followed by two **PHALANGES**, and in digits IV and V, the metacarpals are each followed by three phalanges; thus making a total of five metacarpals and ten phalanges in the hand of the Frog. (W. f. 103.)

The **HIND LIMB** of the Frog and of Vertebrates in general has the same arrangement of parts as the fore limb. There is, first, a large **FEMUR** which is homologous with the humerus in the fore limb. It articulates proximally, as mentioned above, with the acetabulum of the pelvic girdle. The distal end of the femur articulates with the **TIBIO-FIBULA**. This is a single fused bone in the Frog, but in many of the Vertebrates it consists of two separate bones, the **TIBIA** and **FIBULA**. It is homologous with the radio-ulna of the fore limb. The ankle bones (**TARSALS**) of the Frog are atypical. Each of the five digits of the foot begins proximally with a **METATARSAL** bone. In digits I and II, there are two **PHALANGES**

each ; in digits III and V, there are three phalanges each ; in digit IV, there are four phalanges ; thus making in all a total of fourteen phalanges in the foot as compared with ten in the hand. Lying near digit I in the foot of the Frog is an accessory digit, the *CALCAR*, which is a spur-like structure formed from two small bones. (W. f. 103.)

THE VERTEBRATE LIMB. The pentadactyl limbs of the Frog, the structure of which has just been considered, are essentially the same as, and are homologous with, those found in all the higher Vertebrates, including Man. The greatest amount of variation between the limbs of various Vertebrates takes place in the wrist and hand bones of the fore limb, and in the ankle and foot bones of the hind limb ; the larger bones lying nearer the body being somewhat more constant throughout the Vertebrate series. Thus in the fore limb, or wing, of a Bird the humerus, radius, and ulna are all typical, but in the wrist and hand there has been a marked reduction and modification in the bones.

In the hoofed Mammals the structure of the limbs has departed more widely from the pentadactyl type than in most other groups of Vertebrates. Thus in the fore limb of the Horse the humerus is about the only bone that has retained the usual structure. Only a small portion of the ulna is present, and it is fused with the radius. Digits I and V have entirely disappeared. Digits II and IV are present as rudimentary structures, known as *SPLINT BONES*. Digit III remains the sole functional digit, so that the Horse walks on the tips of the third digits. In certain Vertebrates, such for example as Snakes or Whales, the hind limbs and girdles have almost disappeared and are no longer functional. In Man, the limbs have remained true to the pentadactyl type, but there has been a fusion of certain bones in the wrist and ankle. (W. fs. 105, 227, 230, 234.)

C. INTERNAL STRUCTURE

In considering the internal structure of the Vertebrate animal, it will be well to recall the "tube within a tube" condition which was seen to best advantage in the Earthworm. Here we found (*a*) the outer tube, or body wall, composed largely of muscle tissue ; (*b*) the endodermal lined inner tube, or alimentary canal, also largely muscular, running through the body from the anterior to the posterior ends ; (*c*) the many chambered body cavity, or coelom,

lying between the body wall and alimentary canal, and containing the vascular, excretory, reproductive, and nervous systems. (W. fs. 60, 94, 95.)

Fundamentally all the Vertebrates have this same general arrangement of the internal organs. Underneath the skin is the **BODY WALL**, composed largely of muscle tissue or 'flesh.' The body wall of the Vertebrate is much thicker on the dorsal surface than it is on the ventral, but in all regions it forms a continuous and fairly rigid layer. Most of the highly developed organ systems, such as the vascular, excretory, and nutritive systems, are chiefly located in the coelom of the trunk region with extensions to the peripheral regions of the body. The vertebrate coelom, however, consists either of one or two large cavities as compared with many chambers in the Earthworm. (W. fs. 106-109.)

We may now proceed to a consideration of the internal structure of the Frog. In order to do this it will be necessary to lay open the ventral body wall of the trunk region by a median cut, which should extend anteriorly to the girdle, or **STERNUM**, of the fore limbs and posteriorly to the **PELVIC GIRDLE** of the hind limbs. After cutting through the loose outer layer of skin, the structure of which has been noted above, one comes into contact with the muscular body wall. Cutting through this layer opens up the body cavity, or **COELOM**, which is a single large chamber in the Frog, and thus exposes a number of the most important organs of the body, collectively spoken of as the **VISCERA**, which lie in it. Dorsal to the coelom lies the vertebral column, in a specialized portion of which is the central nervous system. This arrangement of the central nervous system, which is typical of the Vertebrates, is very different from that found in the higher Invertebrates in which the nerve cord lies directly in the coelom, close to the ventral body wall. (W. f. 107.¹)

The general arrangement of the organs in the coelom is quite uniform throughout the Vertebrate series, but in the Mammals, including Man, the cavity of the coelom is completely divided by a sheet of muscular tissue, the **DIAPHRAGM**, into an anterior portion, or **THORACIC CAVITY**, in which are the heart, lungs, and esophagus, and a posterior portion, or **ABDOMINAL CAVITY**, which contains the remainder of the viscera. (W. fs. 108, 109.)

¹ In this figure the internal structure of the Frog is viewed from the left side instead of from the ventral surface.

Lying in the anterior end of the coelomic cavity, just below the sternum, is the **HEART**. It is enclosed in a delicate, transparent membrane, the **PERICARDIUM**. On either side of the heart, and extending posteriorly for a considerable distance, are the brownish-colored lobes of the **LIVER** which is one of the most prominent organs in the abdominal cavity. It consists of three main lobes connected by small tubes, the **HEPATIC DUCTS**, which communicate with a common **GALL BLADDER**. The latter can be noted as a small, green sac lying between and slightly dorsal to the lobes of the liver. The pair of thin-walled **LUNGS** can be seen lying posterior to and on either side of the heart. (W. fs. 107, 112.)

Projecting posterior to the liver, the **STOMACH** can be seen. The anterior, **CARDIAC PORTION** merges without very great differentiation into the **ESOPHAGUS** which leads to the mouth. The posterior, **PYLORIC PORTION** of the stomach is somewhat smaller than the cardiac portion. It ends at a definite constriction, the **PYLORUS**, at which point the coiled **SMALL INTESTINE** begins. The first loop of the small intestine curves anteriorly and, together with the pyloric end of the stomach, forms a U-shaped structure, between the two sides of which the important digestive gland, the **PANCREAS**, is situated. The latter is an elongated, yellowish body. The **COMMON BILE DUCT** from the gall bladder passes through the pancreas, the ducts of which it receives, and then opens into the small intestine near the anterior end. The small intestine can be traced posteriorly, through a number of coils, to where it enlarges to form the **LARGE INTESTINE**, or **RECTUM**, which merges into the **CLOACA**. The latter opens to the exterior. Lying near the anterior end of the rectum, a small, reddish body, the **SPLEEN**, is to be seen. The stomach and intestines are suspended in the coelom by membranous sheets, known as **MESENTERIES**, which surround the walls of the intestines, and which are also continuous with the layer, termed the **PERITONEUM**, which lines the coelom. (W. fs. 107, 112.)

The **UROGENITAL SYSTEM**, consisting of the **KIDNEYS**, **BLADDER**, **GONADS**, and associated **DUCTS**, lies near the dorsal wall of the coelom toward the posterior end. There is a pair of elongated, brownish-colored kidneys, one of which lies on either side of the coelom. On the ventral surface of each kidney is a thin strip of orange-colored tissue, the **ADRENAL BODY**. The adrenals are among the most important of the **DUCTLESS GLANDS**, and give off an essential secretion directly into the blood. A very small duct, the **URETER**,

passes posteriorly from the lateral edge of each kidney and opens into the cloaca. The cloaca is a common chamber into which the intestinal, urinary, and genital ducts open. It is really the modified posterior portion of the rectum, and is present in most Vertebrates, except in the higher Mammals. The urinary bladder also opens into the cloaca opposite to the ureters. (W. fs. 107, 132.)

The kidneys have the same structure in both sexes, but the structure of the gonads as well as the arrangement of the ducts are somewhat different. In the male Frog, the TESTES are seen as a pair of small oval bodies, one attached near the anterior end of each kidney. Ducts from the testes lead into the kidney ducts and connect with the ureters. Thus in the male Frogs, the latter serve as a common duct for both the kidney secretions and the sperm, and are, therefore, designated as the UROGENITAL CANALS. A pair of yellowish, finger-like structures, known as the FAT BODIES, are to be seen attached near the anterior end of each testis.

In the female Frog, lying in the same region as the testes in the male, is a pair of lobulated OVARIES with the FAT BODIES attached to the anterior ends. A pair of comparatively large, white, convoluted OVIDUCTS is present, neither of which is directly attached to the ovaries. Anteriorly each oviduct begins as a funnel-shaped, ciliated opening situated near the anterior end of the coelom and enlarges posteriorly to form a uterus which opens into the cloaca. In the breeding season the ovaries are very large and fill up a great portion of the body cavity. (W. f. 132.)

D. ORGAN SYSTEMS

1. *Nutritive System*

The plan of structure of the alimentary canal in the Frog or in any other Vertebrate is fundamentally the same as that which was noted for the first time in the study of the Earthworm, and then later in other of the higher Invertebrates. In all these animals, stated in the simplest terms, the alimentary canal consists of a tube lined with mucosa, which begins with the mouth at the anterior end, runs through the body, and ends posteriorly at the anal opening. This tube may be straight as in the Earthworm or greatly coiled as in the Clam and, in general, in the Vertebrate animals. (W. pp. 150-160.)

In the Frog the mouth, or **BUCCAL CAVITY**, which is the specialized anterior end of the alimentary canal, is comparatively large and contains several noteworthy structures. The highly developed, muscular **TONGUE** lies in the center of the lower jaw and extends from near the extreme anterior end to the posterior part of the mouth. It is attached to the ventral wall of the mouth at the anterior end only. As a result of this type of attachment, the free posterior end of the tongue can be extended quite a distance out of the mouth and thus made use of in the capture of Insects or other small animal forms for food. The extension of the tongue is accomplished by rapidly filling a lymph space which lies beneath it. Posterior to the tongue, on the ventral wall of the mouth, is a raised, circular body which has a slit-like opening, the **GLOTTIS**, leading from the mouth cavity into the larynx and then to the lungs. Also, on either side near the posterior end of the tongue of the male Frog of some species there is a small opening through which air passes into the **VOCAL SACS**. The latter are known to act as resonators and thus increase the volume of sound. (W. f. 107.)

In the posterior part of the upper jaw on either side is the opening of an **EUSTACHIAN TUBE** which leads to the cavity of the middle ear. Anterior to the openings of the Eustachian tubes is a pair of olfactory openings (**INTERNAL NARES**) which connect with the external nares, and lying between are two groups of teeth, known as the **VOMERINE** teeth. Numerous other very small teeth are borne around the margin of the upper jaw. The teeth of the Frog are not used as masticating organs, but function solely for holding food which has been captured. The bony portion of the upper jaw is enclosed by a fleshy upper **LIP**. The latter is lacking in the lower jaw, so that when the mouth is closed the lower jaw fits into a groove, the **SULCUS MARGINALIS**, inside the upper lip.

The buccal cavity ends posteriorly in the **PHARYNX** which soon merges into the **ESOPHAGUS**. The latter continues as a small, undifferentiated tube through the anterior part of the coelom and then enlarges, as has been noted, to form the **STOMACH** which lies chiefly on the left side of the animal's body. The stomach gradually decreases in size toward the posterior end and curves somewhat toward the right side of the body.

The **SMALL INTESTINE** consists of two portions: namely, the anterior portion, known as the **DUODENUM**, which connects with the pyloric end of the stomach; and the posterior portion, known as the

ILEUM. There is no external differentiation to be noted between these two portions. The duodenum curves anteriorly and forms with the stomach a U-shaped structure. When seen from the ventral side, the duodenum forms the left side of the U. The common bile duct carrying the materials from liver and pancreas opens into the duodenum a short distance below the pylorus. The ileum begins at the upper left-hand corner of the U and then curves abruptly posteriorly, forms a number of coils, and finally enlarges to form the **LARGE INTESTINE**. (W. f. 112.)

A microscopical study of a prepared section through the wall of the small intestine reveals the fact that it is composed of several distinct layers of tissue which may now be described. (a) The small intestine is covered by a thin layer, the **SEROSA**. (b) Below the serosa is a double **MUSCULAR LAYER** composed of a thinner layer of longitudinal muscle fibers and a thicker layer of circular muscle fibers. (c) Within the muscular layer is the **SUBMUCOSA**, which consists of connective tissue and vascular elements. (d) Finally, the tube is lined by the essential **MUCOSA**, which is of endodermal origin and consists of a single layer of cells, some of which are specialized for the secretion of the digestive enzymes and some for the absorption of the digested food materials. The wall of the stomach has the same general arrangement. (W. f. 34.)

Although, as previously stated, the essential structural features of the alimentary canal remain uniform throughout the Vertebrates, there are certain noteworthy modifications, some examples of which may be noted. These may be regarded as adaptations to the type of food or to the eating habits of the organism in question. In certain Fishes the intestine is provided with devices which retard the passage of materials and at the same time increase the absorptive surfaces, just as has been seen in the typhlosole of the Earthworm. The so-called **SPIRAL VALVE** of the Shark is a good example. It consists of a membranous fold of tissue, which hangs down into the intestinal cavity. As the name indicates, the attachment to the wall of the intestine is of a spiral nature. The result is that the food materials in process of digestion are forced around and around the interior of the intestine as they are slowly moved posteriorly. In other Fish, as, for example, in the Perch, the same result is obtained by the presence of several blind sacs (**PYLORIC CAECA**) which open from the small intestine near the pyloric end of the stomach. (W. f. 106.)

The alimentary canal of the plant-eaters is larger and more specialized than that of the flesh-eaters. This is seen to advantage in certain Ungulates, the grazing cud-chewing animals, or Ruminants, such as the Cow and Sheep. In such cases a four-chambered stomach is present and so arranged as to permit the hastily eaten plant tissues, or cud, to be regurgitated for a thorough mastication which is a necessary process if digestion is to occur. From the functional standpoint this condition reminds one at once of the condition already noted in the Bee and Ant which permits the regurgitation of the temporarily stored nectar.

In Man, the alimentary tract corresponds quite closely to that of the carnivorous animals. From the pharynx the esophagus extends to the muscular sac which constitutes the stomach. The small intestine is greatly coiled and is about 20 feet in length and two inches in diameter. It joins the large intestine, or COLON, in the lower right portion of the abdominal cavity. The large intestine is about five feet in length and somewhat larger in diameter than the small intestine. It begins with a blind sac, or CAECUM, to which the tubular VERMIFORM APPENDIX is attached. The latter is a closed sac, normally about four inches in length, apparently non-functional, and often the seat of a serious infection, appendicitis. From the caecum the large intestine runs first anteriorly (ASCENDING COLON), then crosses to the left side of the body (TRANSVERSE COLON) and, finally, proceeds posteriorly (DESCENDING COLON) and dorsally through the short straight rectum to the anal opening. (W. fs. 109, 110.)

FUNCTIONAL. While the food of adult Frogs normally consists, for the most part, of small living animals, such as Insects or Worms, it is known that they will readily devour almost any kind of food which they can get into their mouths. They are cannibalistic, and a large Frog will devour smaller individuals when the opportunity presents itself. The structure of the tongue, as previously noted, is of such a character that the posterior end of it can be very quickly thrust out from the mouth. The Frog is able to capture even a rapidly moving Insect with this peculiar weapon. In such cases, after contact has been established, the prey is held to the tongue by a sticky secretion and drawn back into the mouth.

The ingested food is passed directly from the mouth, through the esophagus, and into the stomach where, in the Frog, the first stage of digestion begins. The movement of the food throughout

the length of the alimentary canal is brought about by PERISTALSIS which consists of a series of progressive waves of reduction in the diameter of the tube as a result of the contraction of the layer of circular muscle fibers in the walls. The peristaltic movement begins anteriorly and sweeps posteriorly, forcing the food materials along with it.

The movements of the muscular walls of the stomach are of such a character as thoroughly to mix the food with the secreted enzyme, PEPSIN. This ferment, working in a slightly *acid* medium, due to the presence of a small amount of hydrochloric acid, is able to begin the process of digestion of the protein materials and to change them into PEPTONES. Both the pepsin and the hydrochloric acid are secreted by the endodermal glands noted above.

When the proper condition of the food has been obtained, the pyloric valve opens, and the partially digested food is passed through it and into the duodenum. Here it is acted upon by the digestive fluids secreted by the pancreas and carried to that region by the common bile duct, and also by those present in the intestinal juices. The pancreatic juice contains three principal digestive agents as follows: (1) TRYPSIN, which further acts on the peptones and completes their digestion; (2) AMYLOPSIN, which acts on the starches and changes them into sugar, and (3) LIPASE, which acts on the fats, splitting them into a fatty acid and glycerol. The digestive action of the pancreatic enzymes is dependent upon an *alkaline* condition of the food, and this is largely brought about by the strongly alkaline pancreatic juice. The food materials from the stomach with an acid reaction are mixed with this alkaline secretion before the final phases of digestion take place. When digestion is completed, the liquid food is absorbed by the cells of the mucosa lining the intestine and then turned over to the vascular system for transportation to all regions of the body.

The essential features of digestion are the same throughout the vertebrate series, but certain variations are to be noted in the regions utilized and the enzymes employed. Thus, in Man and other Mammals, the digestion of starchy foods begins in the mouth through the action of the enzyme PTYALIN, which is present in the saliva. The final stage of starch digestion occurs in the small intestine just as in the Frog. Other important enzymes present in the intestinal secretion are EREPSIN which completes the digestion of the proteins begun in the stomach; and MALTASE, SUCRASE, and

LACTASE, all of which are concerned with the final stage of carbohydrate digestion. (W. f. 113.)

THE FUNCTIONS OF THE LIVER. The liver, which is the largest gland in the body, has several important functions particularly in connection with nutrition. In the first place, it secretes the bile which together with alkaline pancreatic juice aids in overcoming the acidity of the food from the stomach. It is known that certain substances in the bile play additional rôles in converting starch into sugar, and also in emulsifying fats so that they can be absorbed from the intestine without being chemically changed. Undoubtedly, bile also contains a large amount of excretory materials.

Furthermore, the liver has the power of synthesizing GLYCOGEN, or 'animal starch.' This carbohydrate is normally formed from sugar, but protein material can also be utilized. It will be shown below in the study of the vascular system that the liver receives the blood containing all absorbed food materials, except the fats, directly from the digestive tract through the hepatic portal vein, and it is thus enabled to abstract the materials for the formation of glycogen. In a well-fed animal, the liver contains considerable amounts of glycogen which can be supplied to the cells of the body as needed. Before being released into the blood stream, the glycogen is changed into dextrose by the action of a specific enzyme in the liver. Finally, the liver aids in the process of excretion by changing the nitrogenous waste products in the blood into UREA, which is later taken from the blood by the kidneys. (W. f. 115.)

2. *Respiratory System*

In the adult Frog the chief organs for the interchange of the gases concerned with the respiratory function are the skin and lungs. It is a question which one is the more important, but it is probable that more carbon dioxide is given off through the skin than through the lungs, and in the winter, when the Frogs are hibernating, the entire burden of the reduced respiratory exchange is carried on by the skin. The wet, mucus-covered skin of the Frog is highly vascularized, and the blood is brought into close contact with the oxygen which may be present either in the surrounding air or water as the case may be. The excess carbon dioxide is given off, the essential oxygen picked up and transported to the cells of the body where respiration takes place. (W. pp. 161-167.)

The lungs of the Frog consists of a pair of thin-walled distensible

sacs as previously noted. The outer surface of the lungs is smooth, but the inner lining is thrown into folds, or wrinkles, which form tiny air-cavities, or ALVEOLI, over the entire inner surface. All of these open into the central cavity, and it receives the air from the mouth cavity. The walls of the alveoli are richly supplied with blood vessels, and it is through these walls that the necessary interchange of gases takes place. (W. f. 107.)

Anteriorly each lung opens into the common TRACHEAL CAVITY, and the latter communicates directly with the mouth cavity through the tiny slit-shaped opening, or glottis, in the ventral wall of the mouth, as previously noted. Just below the glottis, the walls of the tracheal cavity are strengthened by cartilages which are in turn connected to muscles. This region constitutes the voice box, or LARYNX. A pair of VOCAL CORDS, like elastic bands, are so attached to the sides that they vibrate when the air, expelled from the lungs, rushes past them. In this way sound is produced, not only in the Frog, but generally in the Vertebrates. The pitch of the sound can be altered by varying the tension of the cords through the muscular action.

When the respiratory movements are observed in a living Frog, two distinct types can be seen. In the first type, which is confined to the mouth only, there is an almost continual up and down movement noted of the ventral muscular wall of the mouth. This results in the alternate expansion and contraction of the mouth cavity and a consequent intake and outflow of air through the external nares. The mouth is always kept closed except when feeding. In fact it is known that breathing cannot occur if the mouth is forcibly kept open, and the Frog will die of asphyxiation. Air coming from the lungs periodically is gradually released to the exterior as stated above. Thus the mouth cavity always contains air, and undoubtedly considerable respiratory interchange takes place through the epidermal lining tissues.

In the main, during the respiratory movements affecting the lungs, which occur at variable periods, the external nares are closed, the glottis opened, and a much heavier contraction of the ventral mouth wall takes place. The imprisoned air in the mouth cavity is thus forced through the glottis and into the lungs. The periodical expiration of the air from lungs into the mouth cavity is largely brought about by a contraction of the muscular body wall in the fore leg region.

The respiratory, or breathing, movements in the Frog are different from those found in Man or other higher Vertebrates, but the end result is the same in either case, namely, the supplying of the specialized lung tissues with fresh air so that the respiratory exchange can take place. The main feature of breathing in Man is based on changes in the size of the thoracic cavity in which the lungs lie. The thoracic cavity is enlarged by muscular action which pulls the ribs up and out with a synchronous lowering of the diaphragm. Air, impelled by the atmospheric pressure of 15 pounds per square inch, rushes through the external openings, pharynx, trachea, and then into the alveoli of the lungs where the respiratory interchange takes place. It is expelled by a contraction of the thoracic cavity, which results from the lowering of the ribs and the elevation of the diaphragm. (W. fs. 118, 119.)

The normal air capacity of the human lung is approximately 3500 cc. (about 230 cu. inches). By effort this capacity can be increased to about 4000 cc. It is impossible completely to empty the lungs by expiration, some 1500 cc. of residual air remaining at all times. At each inspiration and expiration approximately 500 cc. of tidal air is moved.

FUNCTIONAL. Frequent attention has been called to the fact that the essential feature of respiration, namely, the continuous interchange of gases between the protoplasm of an organism and its environment, takes place in every one of its living cells. It has also been observed in the higher Invertebrates that both a specialized respiratory mechanism and a system of transportation are necessary features of cell respiration. These basic facts remained unaltered in the Frog and other Vertebrate animals. We have just noted the structural features of the lungs, and in the next section, consideration will be given to the vascular system as the great transporting medium to and from the cells, not only of the respiratory gases, but of the numerous types of materials which are necessary for the life-processes of the organism.

It may be well to call attention at this point to one characteristic of the Vertebrates which is of fundamental importance in transporting to the cells the oxygen necessary for respiration, namely, the red corpuscles which contain the remarkable compound **HEMOGLOBIN**. This complex substance has the ability to form an unstable compound (**OXYHEMOGLOBIN**) with oxygen in the lungs where the oxygen is abundant, and it is in this form that a great

proportion of the oxygen is conveyed to the tissues of the body. Here the unstable oxyhemoglobin in the red corpuscles is broken down, and the free oxygen passes through the walls of the capillaries and is taken up by the tissue cells. The red cells containing the hemoglobin are then returned to the lungs and the process is repeated.

3. *Vascular, or Circulatory, System*

The vascular system of the Frog and of the Vertebrates in general has the general structural features of the vascular systems that were noted in the various higher Invertebrates. Thus we find that it consists essentially of a connected, closed system of muscular-walled tubes, or **BLOOD VESSELS**, together with a circulating fluid medium, the **BLOOD**. The blood is continuously propelled through the vessels by the rhythmic contractions of the **HEART**. The latter is to be regarded as a blood vessel which has become adapted for this particular function by the development of a special type of muscular tissue. It is the dynamic and all important center of the system. The blood vessels are divided into **ARTERIES**, which carry blood away from the heart; **VEINS**, which carry blood to the heart; and **CAPILLARIES**, which connect the arteries and veins together in the tissues, through an amazing network of thin-walled, microscopic vessels. Blood leaving the heart must always make the complete circuit involving certain arteries, capillaries, and veins before it again reaches the heart. (W. pp. 168-179.)

In addition to the closed circulatory system, as just noted, and of fundamental importance is the open **LYMPHATIC SYSTEM** which consists primarily of various sized lymph spaces, channels, and thin-walled **LYMPH VESSELS** through which a fluid derivative of the blood, the **LYMPH**, slowly moves. The system is so arranged that every cell in the organism is bathed by this lymph, so that in the transfer of materials to and from the cell, the lymph stands as the final agent.

BLOOD. We may now consider certain structural features of the vascular system in more detail. The blood may be regarded as a liquid tissue, that is, a tissue in which the intercellular material is of a liquid rather than a solid nature. In all other tissues of the organism, the intercellular material holds the cells rigidly in place. The blood is composed of a liquid substance, or **PLASMA**, which contains enormous numbers of various types of highly developed blood

cells, or CORPUSCLES. Although blood plasma is composed of about ninety parts of water and ten parts of solid materials in solution, it is in reality a highly complex medium and marvelously fitted for the transportation of various essential materials. In addition, it possesses an intricate arrangement which results, when necessary, in clotting, or coagulation — an important process which controls bleeding as will be noted later. Since the plasma continually receives and gives off an almost infinite variety of materials in its relations with the cells, the exact chemical composition varies continuously and, therefore, an exact analysis can never be obtained.

The blood corpuscles comprise two main types of living cells, the RED CORPUSCLES and the WHITE CORPUSCLES, or LEUCOCYTES. The red corpuscles are so-called because they contain the complex red pigment, hemoglobin, which has a strong affinity for oxygen, and is necessary for its transportation from the skin or lungs to the cells of the body. They may be described as tiny, biconcave disks with a central oval-shaped nucleus. In the higher Vertebrates, the nucleus is lacking in the mature red cell.

There are several varieties of white corpuscles which show considerable variation in size, form, character of nucleus, and function. In general, however, these cells are amoeboid in character. There is no definite cell wall, the shape is variable, and they move and capture food by temporary pseudopodia-like projections. They function primarily in the control of infection through the actual ingestion (PHAGOCYTOSIS) of the invading organisms. (W. f. 7, C.)

HEART. The heart of the Frog consists of three chambers, namely, a VENTRICLE and two AURICLES. Thus in its structure it may be said to occupy a middle position between the two-chambered fish heart and the four-chambered heart of the higher Vertebrates. The thick-walled, conical-shaped VENTRICLE lies posterior. This is the main pumping part and, by its rhythmical contractions, drives the blood through the arteries to all parts of the body. Anterior to the ventricle there are two thinner-walled cavities, the AURICLES, one to the right and one to the left. Opening into the right auricle, on the dorsal surface of the heart, is a large triangular sac, the SINUS VENOSUS, which receives blood from all parts of the body through three veins; from the anterior regions through the right and left ANTERIOR VENA CAVA, and from the

posterior regions through the POSTERIOR VENA CAVA. Opening into the left auricle are the PULMONARY VEINS which bring blood to the heart from the lungs. Leading from the ventricle is a vessel with heavy muscular walls, the CONUS ARTERIOSUS, which branches soon after leaving the heart and forms three pairs of important arteries noted below. All the blood from the ventricle passes out through the conus arteriosus. The heart, as noted in a previous section, is enclosed by a transparent membrane, the PERICARDIUM. (W. f. 121.)

The heart of the Bird and Mammal has four chambers; a right and left auricle and a right and left ventricle. The right and left sides are completely separated by a tissue wall so that there is no possibility of mixing the blood in the ventricles as in the Frog heart. The venae cavae open directly into the right auricle. The latter communicates with the right ventricle through the TRICUSPID VALVE. The right ventricle, which is larger and heavier walled than the auricle, communicates through the pulmonary artery with the lungs. Into the left auricle open the pulmonary veins from the lungs. The opening between the left auricle and left ventricle is guarded by the MITRAL VALVES. The cavity of the left ventricle communicates through the aorta with the general systemic circulation. The walls of the left ventricle are very muscular. (W. fs. 121, 123.)

VEINS. The three largest veins in the Frog are the right and left ANTERIOR VENA CAVA and the single POSTERIOR VENA CAVA, all of which open into the SINUS VENOSUS. Emptying into the anterior venae cavae are smaller veins which receive the blood from all the anterior parts of the body except the lungs as follows: Blood from the mouth region is collected by a pair of veins, the EXTERNAL JUGULARS; from the brain and other parts of the head region by a pair of INTERNAL JUGULARS; from the shoulders by a pair of SUBSCAPULARS; from the fore limbs by a pair of BRACHIALS; and from the side of the body and certain portions of the head by a pair of MUSCULO-CUTANEOUS veins. The blood from all of these veins finally empties into either the right or the left anterior vena cava, from which it passes into the sinus venosus.

Posteriorly the blood is received into the posterior vena cava from the liver through the HEPATIC VEINS, and from the kidneys and reproductive organs through the RENAL VEINS. Emptying into these vessels are those which received blood from the body

wall, hind limbs, etc., as follows: The liver receives venous blood from (a) the single, median ABDOMINAL VEIN, which in turn arises from a pair of PELVIC VEINS; and from (b) the intestinal tract through the HEPATIC PORTAL VEIN. The kidney receives venous blood from a pair of RENAL PORTAL VEINS which arise from the FEMORAL and SCIATIC VEINS of the hind limbs. (W. f. 121.)

ARTERIES. The CONUS ARTERIOSUS, which as previously noted leads from the ventricle, supplies all the arteries in the body. It passes anteriorly from the ventricle and, just beyond the anterior edge of the auricles, divides to form a right and left branch, from each of which arises three arteries; thus forming a total of six main arteries, or three pairs, from the heart. These are designated as a pair of COMMON CAROTIDS, a pair of PULMOCUTANEOUS, and a pair of SYSTEMIC ARCHES.

Each of the COMMON CAROTID arteries divides into an EXTERNAL and an INTERNAL CAROTID, and these run anteriorly and supply the entire head region. They each give off a number of branches as they proceed. The PULMOCUTANEOUS ARTERIES carry blood to the respiratory organs. Each divides into two main branches, one of which runs to the lungs (PULMONARY ARTERY) and the other (CUTANEOUS ARTERY) to the skin and body wall. Each of the SYSTEMIC ARTERIES curves dorsally and posteriorly. Posterior to the heart, and close to the dorsal body wall, the two arches unite to form a single large vessel, the DORSAL AORTA, from which branches arise that supply the important abdominal organs, the muscles of the abdominal body wall, and the hind legs. Before uniting to form the dorsal aorta, the right and left systemic arches on each side give off two branches: (a) the OCCIPITO-VERTEBRAL, from which arise the OCCIPITAL ARTERY supplying the jaws and nose, and the VERTEBRAL ARTERY which runs to the vertebral column; and (b) the BRACHIAL ARTERY which is distributed to the fore limb of that side and to the body wall near by. (W. f. 121.)

PORTAL SYSTEMS. Attention should be called to the RENAL PORTAL SYSTEM and the HEPATIC PORTAL SYSTEM. The renal portal system consists of a pair of veins which carry blood from the hind limbs to the kidneys. Into each of these renal portal veins three vessels empty: a FEMORAL and a SCIATIC VEIN from the hind leg, and a small DORSOLUMBAR VEIN from the body wall. Thus, in the Frog the venous blood from the hind limbs and from a portion of the body wall, instead of emptying directly into the vena cava,

passes by way of the renal portal vein into the kidneys. In Mammals the renal portal system is lacking. (W. f. 121.)

The hepatic portal system consists of a single large vessel, the **HEPATIC PORTAL VEIN**, which receives the venous blood with absorbed foodstuff from the alimentary tract by means of the **INTESTINAL**, **DUODENAL**, and **GASTRIC** veins. This blood is then passed into the liver. After passing through the liver it is collected by the hepatic vein, thence into the posterior vena cava. In addition to the blood received from the alimentary tract through the portal vein, the liver also receives a considerable supply of venous blood directly from the hind limbs, body wall, etc., through the **ABDOMINAL** vein. (W. fs. 115, A; 121.)

LYMPHATIC SYSTEM. The importance of the lymphatic system has been noted above. In the Frog, it consists of a connected series of lymph spaces and channels which permeate all the tissues of the body. These range in size from microscopic spaces around the cells to the very large lymph sacs which lie just under the skin in various parts of the body. Connected with certain of the larger lymph sacs are four special areas of contractile muscle tissue which constitute the **LYMPH HEARTS**. They pump the lymph back into the regular blood stream through certain veins. (W. fs. 124, 125.)

The lymphatic system in the higher Vertebrates is characterized by the development of numerous thin-walled lymph vessels which connect with the lymph spaces. The lymph vessels empty into the large **THORACIC DUCT** which opens into the left jugular near the heart. There are no definite contractile elements in this system, and the flow of lymph through the thoracic duct and into the regular blood channels is irregular and more or less dependent upon the character of the body movements. (W. f. 115.)

COURSE OF CIRCULATION IN THE FROG. The general course of the circulation in the Frog is as follows (W. 121, B):

The venous blood from all parts of the body, with the exception of the lungs, flows into the sinus venosus. The latter is contractile, and it forces the blood into the right auricle. When the right auricle contracts the blood is forced through the auriculo-ventricular aperture and into the right side of the ventricle. By the almost synchronous contraction of the left auricle, the newly oxygenated, or arterial, blood, which has been received from the lungs through the pulmonary veins, is also forced through the

auriculo-ventricular aperture and into the left side of the ventricle. There is more or less chance of mixing the venous and arterial blood in the one-chambered ventricle, but this is minimized by the structure of the ventricle.

The contraction of the ventricle now takes place in such a way that the venous blood from the right side is first forced out through the conus arteriosus. This latter vessel is so arranged that the venous blood is forced into the pulmocutaneous arteries which run to the lungs and the skin. The oxygenated blood from the left side of the ventricle is next forced out, and this blood passes from the conus arteriosus into either the carotid or systemic arteries which, with their branches, supply all the other regions of the body.

Both the arteries and the veins break up in the tissues into a dense network of microscopic, connecting capillaries. A certain amount of the plasma of the blood together with some of the white corpuscles are able to pass through the thin walls of the capillaries into the lymph spaces and thus come into direct contact with the tissues. The portion of the blood which leaves the closed vascular system through the walls of the capillaries is the lymph. The greater portion of the blood, instead of passing through the walls of the capillaries, continues its more rapid course through the capillaries and then into a vein leading back to the heart.

COURSE OF CIRCULATION IN THE MAMMAL. The general course of the circulation in Mammals is the same as in the Frog, but the complete separation of the right and left sides of the heart has established a pulmonary circulation which is independent of the systemic circulation. Blood from all parts of the body, except the lungs, is received directly into the right auricle from the superior and inferior vena cava. The contraction of the auricle forces the blood through the tricuspid valves into the right ventricle, from where it passes through the pulmonary artery into the lungs for oxygenation. Leaving the lungs, the blood returns to the left auricle through the pulmonary veins and thus completes the pulmonary circulation. (W. f. 121, C.)

The contraction of the left auricle drives the oxygenated blood through the mitral valve and into the left auricle. The strong contractions of the latter drive the blood, under considerable pressure, through the aorta and to the tissues of the body. In the latter it passes through the capillaries, then into a connecting vein and back to the heart, and thus completes the systemic circulation.

One of the most interesting demonstrations of the functioning of the vascular system is to be seen when a small portion of the living interdigital web of the Frog's foot is observed under the microscope. In such a demonstration, the characteristics of the flow of blood through the arteries, capillaries, and veins can easily be seen. Thus, it will be noted that the flow is most rapid through the arteries, where a definite pulsation can be detected which, of course, results from increased pressure due to the contraction of the ventricle. The flow in the veins is much slower and no pulsation is noted. The capillaries will be seen as very tiny vessels through which the red corpuscles have to pass in single file. All in all, an amazing impression of the vitality and omnipresence of the vascular system is presented.

FUNCTIONAL. Our previous consideration of the vascular system has shown that it is responsible for the transportation, to and from the cells, of all essential materials. In order to get the details clearly in mind, it will be well to enumerate the chief items transported, the methods of transportation, and the relations to other life functions. (W. f. 126.)

Nutrition. The soluble food materials absorbed from the alimentary canal by the mucosa cells are carried in solution in the blood plasma and, except for the fats, go first to the liver through the portal vein, where the digested carbohydrates are temporarily removed and changed into glycogen by the hepatic cells. The latter is replaced in the blood stream from time to time in such amounts as are needed to supply the demands of the cells for 'quick energy.' Various amino acids, resulting from the digestion of the proteins, are present in the blood plasma, and each cell selects the particular ones necessary for the manufacture of its specific protoplasm. Fats are largely absorbed by the lymphatics (LACTEALS) in the villi of the intestine and pass through the thoracic duct and then into the blood stream. (W. fs. 114, 115.)

Respiration. The blood of the Vertebrate transports the essential and continuous supply of oxygen obtained from gills, lungs, or skin, almost entirely in the red corpuscles, where, as previously noted, it combines with the hemoglobin to form oxyhemoglobin — an unstable compound which lasts only until the oxygen-deficient cells are reached. The oxyhemoglobin formed in the red corpuscles gives arterial blood its bright red color. The carbon dioxide ex-

creted from the cells is transported in the plasma, mostly in the form of sodium bicarbonate, to the lungs, gills, or skin.

Excretion. It is believed that all the excretory products of the cells are carried in solution in the plasma. These consist of the carbon dioxide, already considered in connection with respiration, nitrogenous wastes, and various inorganic salts in solution. These nitrogenous and inorganic wastes are for the most part given off into lymph by the contiguous cells, and reach the blood plasma indirectly. The nitrogenous wastes are removed from the blood stream by the selective action of the liver cells which change them into UREA and then return them again to the blood stream. The urea, as well as the inorganic salts and excess water, are removed from the blood stream by the specialized cells of the kidney tubules and then passed to the exterior. The sweat glands in the skin also remove considerable quantities of excess water, containing small quantities of urea and salts, from the blood stream.

Secretion. The blood plasma carries the secretions, or HORMONES, formed by the ductless glands, or endocrine organs, examples of which will be noted in a later section. The hormones are of vital importance in the economy of the organism and must be present at all times in the blood stream, so that the tissue cells can secure the necessary ones. For example, the absence of the thyroid hormone will bring on a gradual deterioration and general breakdown of nerve tissue, while the absence of an almost infinitesimal amount of the parathyroid hormone will almost immediately throw the organism into violent paroxysms ending very quickly in death.

Infection. The control of infection, which is due to the invasion of some disease-producing organism, is largely a function of the vascular system. This may be said to be accomplished in two ways. In the first place there are certain chemical substances in the plasma of the blood and lymph known as ANTIBODIES. Their exact nature is unknown, but apparently they are able to render the environment unsuitable to the invading organism. If the parasitic organism does get a foothold, then more and more antibodies are produced, presumably by the cells of the host, and given off into the blood stream, until the disease is overcome.

Another method of disease control is through certain of the white corpuscles, or leucocytes, which, as noted above, are amoeba-like in structure and habits. At the time of an infection they are

formed in great numbers in the blood, and they congregate at the focus of infection and actually eat up, or phagocytize, the invading bacteria. They are aided in this work by a particular type of antibody, the OPSONINS, present in the plasma which makes the bacteria palatable, as it were, to the leucocytes.

Of course, it is the lymph which actually bathes the cells and comes into immediate contact with the infected areas and the invading organism. The lymph, it should be emphasized, contains both antibodies and leucocytes and is a first line of defense against invasion. But the lymph itself in an infected area may pick up some of the parasites or other substances harmful to the other tissues of the host. Such lymph must not be permitted to enter the blood stream for general circulation until the foreign materials have been rendered harmless. This is the function of the LYMPH NODES which are present at strategic points in the lymphatic system. The lymph slowly filters through them and the cells of the nodes are usually able to render the lymph sterile before passing it on to the blood stream. (W. f. 124.)

Temperature control. The continuous and rapid flow of the blood stream through all the tissues of the body serves to keep all parts at a fairly uniform temperature. In general, however, the blood picks up excess heat in the tissues, particularly muscle tissue, where rapid metabolism is occurring, and it dissipates this heat at the surface of the body through the skin. In the case of the so-called cold-blooded animals, like the Frog and, in fact, all the Vertebrates except Birds and Mammals, there is no constant body temperature; it varies according to the temperature of the environment. Hence the vascular system is not so important in connection with body temperature as it is in the warm-blooded animals in which the temperature must not be permitted to vary more than a slight amount. Here the vascular system plays an all-important rôle under the direction of the nervous system, the basic feature of which is a variation in the amount of blood sent to the surface of the body. This is accomplished by changes in the size of the skin vessels. If excess heat is being produced, a greater proportion of the blood goes to the skin for cooling. If the external environment is sufficiently cool, the condition of the returning blood will be normal. On the other hand if the temperature of the environment is high, the skin itself will be hot and no cooling will result. In such a case the blood gives up excess water

as perspiration. It evaporates and so cools the skin as well as the blood passing through it. If perspiration is reduced, the temperature of the skin will rise, the blood coming to the surface will not be cooled sufficiently, and the temperature of the body will rise. This may be serious as in the case of a 'sun-stroke.'

Blood Clotting and Wound Healing. The conservation of the blood when injuries occur is, of course, of vital importance if the organism is to survive, and accordingly we find in the plasma of the blood a mechanism which causes coagulation, or clotting. This results in stopping the hemorrhage from the injured tissues, provided the wound is not too large. The solid clot which gradually forms from the liquid plasma is the culmination of a complicated series of reactions which are only imperfectly understood at present. It appears clear, however, that an inciting agent (KINASE) is present in the injured tissues, and it, acting on the calcium salts and PROTHROMBIN in the blood, forms THROMBIN. The latter then reacts with FIBRINOGEN, also in the blood, to form fine, insoluble, needle-like filaments of FIBRIN. A section of a blood clot examined under the microscope reveals the fibrin elements in great abundance throughout the clot, with the blood cells embedded in them. Blood in a dish or other container will normally clot in a few minutes. If it is stirred during clotting the filaments will unite to form long fibers which, together with the enmeshed blood cells, may be removed as a fibrous mass, leaving a blood fluid, the SERUM, which will not clot.

In a wound, the fibrin filaments form a temporary and possibly a permanent union of the tissues. Then the uninjured cells from the nearby tissues move into the area and begin to divide and form new tissues. Leucocytes are also present in great numbers. If bacteria are present they ingest them and thus endeavor to control the infection. They also remove the cell débris resulting from the injured cells.

4. *Excretory System*

The excretory organs of the Vertebrates consist of the lungs, skin, and kidneys. The lungs excrete carbon dioxide and water vapor; the skin excretes small amounts of nitrogenous wastes and various inorganic salts, all of which are in solution; the kidneys excrete the nitrogenous waste, UREA, dissolved in water to form urine as noted below, and salts in solution. Consideration has

already been given in previous sections to the lungs and skin and, therefore, we may now consider the kidneys. (W. pp. 180-187.)

The pair of kidneys of the Frog, or MESONEPHROI¹ as they are technically termed, lie, as has been noted, in the coelom close to the dorsal body wall. The microscopic study of these organs shows that they consist of an enormous number of tiny, coiled, tubular excreting elements, known as the URINIFEROUS TUBULES, which are embedded in connective tissue. Each of these coiled tubes is, in a general way, comparable in its structure to a single nephridium of the Earthworm. In fact, considered from an evolutionary standpoint, the Vertebrate kidney is generally believed to have arisen by a consolidation of the nephridia-like tubules to form the definite kidneys. (W. fs. 107, 132.)

Each uriniferous tubule has at one end a capsule-like structure, known as the MALPIGHIAN BODY. The latter is composed of an enlarged portion of the tubule (BOWMAN'S CAPSULE) which is lined with a peculiar type of cells and encloses a greatly coiled mass of capillaries, and these constitute the GLOMERULUS.² The wastes from the blood are given off in the glomeruli and also in certain other portions of the uriniferous tubules which are invested with a network of capillaries. The question as to the specific functions of these two portions of the uriniferous tubules is somewhat in doubt. (W. f. 131, B.)

The uriniferous tubules of each kidney open into a common collecting canal which, in turn, opens into the ureter. In the Frog, there is no direct connection between the ducts from the kidneys and the bladder; all of which open directly into the cloaca. The arrangement in the cloaca is such that the urine from the ureters finds its way into the opening of the bladder. It collects in that organ and is later expelled from the body through the cloaca. This condition in the Frog is different from that found in Man and other Mammals. In the latter the ureter from each kidney opens directly into the bladder. A tube from the bladder, known as the URETHRA, conveys the urine to the exterior through a separate opening.

Three types of kidneys are recognized in the vertebrate animals, namely, the PRONEPHROS, MESONEPHROS, and METANEPHROS. The structure of all these types is basically the same. That is to say the functional excreting elements are nephridia-like tubules, as

¹ Singular, mesonephros.

² Plural, glomeruli.

described above for the Frog. There is, however, a difference to be noted in the way the wastes from the blood are secured for excretion. In the pronephros, which is the functional kidney in the lowest vertebrates and a temporary organ in the embryos of all vertebrates, there is no direct connection between the uriniferous tubules and the vascular system. Wastes are removed directly from the coelomic fluid through the ciliated nephrostomes as in the Earthworm. In the mesonephros the vascular connection is established in the glomeruli as in the Frog, but remains of the coelomic connection persist. The tubules of the metanephros found in the Reptiles, Birds, and Mammals are connected only with the vascular system, and show no evidence of the condition found in the pronephric and mesonephric types.

The human kidney is a brown, bean-shaped body which lies in the abdominal cavity, close to the dorsal body wall; one on either side of the vertebral column. The internal structure of the kidney is best shown by a median longitudinal section dividing it in half. The examination of the cut surface reveals three distinct regions, namely, an outer CORTEX, a middle MEDULLARY PORTION, and an inner PELVIS. The cortex and the medullary portion are composed of the functional tubules enmeshed in the connective tissue elements for support.

It is found that the glomeruli, together with the convoluted portion of the tubules, lie in the cortex where each is in direct connection through the enclosed capillaries with a tiny branch of the renal artery and the renal vein. The medullary portion of the kidney extends from the outer cortex to the pelvis where it ends in definite projections, the PYRAMIDS. This region consists largely of the lower, or collecting, portions of the tubules, all of which finally open at the tips of the pyramids. The pelvis of the kidney is essentially a reservoir which receives the urine from the countless uriniferous tubules opening through the tips of the pyramids. The urine leaves the pelvis through the URETER which carries it from the pelvis to the bladder. (W. fs. 130, 131.)

FUNCTIONAL. In the Vertebrates, arterial blood containing urea reaches the kidney through the renal artery. In the Frog and many Vertebrates there is also a supply of venous blood received through the renal portal vein. In all cases, the blood having passed through the glomerular capillaries is collected into the renal vein on its way back to the heart. During its passage

through the capillaries contained in the Malpighian bodies and those surrounding the convoluted portion of the tubules, urea and various inorganic salts, both dissolved in water, are removed from the blood, passed through the tubules, and finally reach the bladder through the ureters.

The composite waste product, URINE, consists approximately of 96% water, 1.8% dissolved salts, and 2.2% urea. The last is a white crystalline substance, containing more than 46% nitrogen, and has the chemical formula of $(\text{NH}_2)_2\text{CO}$. It is, of course, readily soluble in water. It will be remembered that the actual synthesis of urea is accomplished by the liver cells; its removal from the blood, by the kidney cells. Both the manufacture and the removal of urea must be carried on continuously. Any impairment of these functions by which the metabolic wastes of the cells are removed will result very quickly in a general systemic poisoning.

5. *Reproductive System*

The sexes in Frogs are separate, but there is no great differentiation in the external structural characters between the male and female. The fore limb of the male is somewhat stouter and the first digit of each hand is somewhat larger. During the breeding season in the spring this digit becomes further enlarged. (W. pp. 188-195.)

MALE REPRODUCTIVE ORGANS. The male organs of reproduction consist of a pair of TESTES in which the SPERM are developed, and numerous fine ducts, known as the VASA EFFERENTIA, which convey the mature sperm cells from the testes into the kidney tubules. Each testis is a yellowish, capsule-shaped body which lies on the ventral side and near the anterior end of each kidney. The vasa efferentia extend into the kidney substance and there connect with the canal system leading to the UROGENITAL CANAL which extends from each kidney to the cloaca. The urogenital canals serve as common ducts for the wastes from the kidneys and the sperm from the testes. Attached to each testis is a yellow FAT BODY. The latter are not directly concerned in reproduction, but serve as storehouses for excess nutriment received during the summer season. (W. f. 132.)

A microscopic examination of a testis shows that it consists of many greatly twisted tubules, together with blood vessels, nerves, and connective tissue elements. The tubules open near

the center of the testis into the vasa efferentia. The other end of each tubule is closed and lies near the outer wall of the testis. The sperm develop from the PRIMORDIAL GERM CELLS situated in the walls of the tubules. The germ cells are typical in structure at first, but after passing through the various stages (SPERMATAGONIA, SPERMATOCYTES, and SPERMATIDS) they become greatly modified cells each of which is made up of (a) a pointed HEAD, containing the male gametic nucleus; (b) a MIDDLE PIECE, containing cytoplasm and centrosome, and (c) a long TAIL, or FLAGELLUM, which has an active, vibratory movement, and enables the sperm cell to move through a liquid with considerable rapidity. (W. f. 133, B.)

FEMALE REPRODUCTIVE ORGANS. The female organs of reproduction consist of a pair of OVARIES in which the EGGS are developed, and a pair of OVIDUCTS which carry the eggs to the cloaca. There is also a pair of FAT BODIES, one of which is attached to each ovary. Each ovary is really a thin-walled sac with an outer covering which is a continuation of the peritoneum lining the entire body cavity. This outer covering encloses a layer of GERMINAL EPITHELIUM containing the PRIMORDIAL GERM CELLS from which the eggs arise. The eggs are more or less grouped and the ovary as a whole has a number of well-defined lobes. The organ is very plentifully supplied with blood vessels. (W. f. 132.)

Each egg cell in the ovary is enclosed by a thin cell wall (VITELLINE MEMBRANE) which is surrounded by several layers of cells (MEMBRANA GRANULOSA). The ovarian egg with the surrounding layers constitutes a GRAAFIAN FOLLICLE. The eggs arise from cells which appear typical. They pass through various stages of development and gradually increase in size until they are several times the size of a somatic, or body cell. This growth results from the gradual accumulation of reserve food material, and is a very common phenomenon in the eggs of many animals. Except for its large size, the mature egg shows a typical cell structure, and is, therefore, very different from the highly modified sperm cell. (W. f. 133, A.)

The eggs of the Frog reach their full development at only one period each year. This is usually in the spring, at which time the two ovaries, distended with masses of eggs, fill up a large portion of the abdominal cavity. When the proper time arrives, the eggs break through the thin ovarian wall and are drawn into the openings of the oviducts. There is no direct connection between the

ovaries and the oviducts as in the case of the testes and the vasa efferentia.

Each of the coiled, tubular oviducts ends anteriorly in a ciliated, funnel-shaped opening. These openings lie in the anterior end of the coelom, one on either side of, and a considerable distance anterior to, the ovaries. The action of the cilia in the funnels is such as to cause a current to flow into them, and thus the eggs are drawn into the oviducts. At the posterior end of each oviduct before it opens into the cloaca there is an enlarged portion, known as the UTERUS, in which the eggs collect, after passing down the oviduct, and remain for a time before being discharged from the body. During their passage through the oviducts the eggs are coated with several layers of jelly which are secreted by glands in the walls of the oviducts. The fertilization of the gametes and the development of the zygote will be considered in the later section on Vertebrate Development. (W. f. 132.)

6. *Endocrine System*

In the Frog and other Vertebrates there are a number of very important glandular bodies, variously known as DUCTLESS GLANDS, ORGANS OF INTERNAL SECRETION, or ENDOCRINE ORGANS. Structurally they are all characterized by the absence of ducts, so that the secretions which they manufacture, known as HORMONES, or INTERNAL SECRETIONS, are passed directly into the blood stream which carries them to all the tissues of the body. The cells of the various tissues select from the blood the specific hormone which is essential to their welfare. Remarkable results have been obtained within the last few years by the investigations upon the various endocrine organs, but even so our knowledge of them and of their physiological actions is limited. This much is clear, however, that the ductless glands — undoubtedly controlled in the final analysis by the nervous system — exercise through their secretions, the hormones, a considerable coördinating and controlling influence upon various tissues and organs — a function which is generally known as chemical coördination. Some of the more important of the ductless glands may now be noted. (W. pp. 196–198.)

THYROID GLANDS. These consist, in the Frog, of a pair of tiny, spherical bodies of a yellowish color, situated in the throat region quite close to the larynx. They are richly supplied with vascular

tissue. Studied microscopically the thyroid tissue is found to consist essentially of vesicular structures, termed FOLLICLES. The walls of the follicles are composed of a single layer of epithelial cells enclosing a central cavity. The latter contains a secreted, transparent material, known as the COLLOID SUBSTANCE, in which there is the hormone, THYROXINE. It is rich in iodine, and is apparently formed as a secretion by the epithelial cells which constitute the walls of the follicles.

The blood, which passes through the thyroid glands, picks up thyroxine which is important in the life of the organism. It has been definitely shown in the Frog that this substance has a specific action upon the process of metamorphosis. If there is a lack of it, metamorphosis will be inhibited. On the other hand, by supplying this hormone to young tadpoles, metamorphosis can be brought about at a very early stage. In Man a deficiency of thyroxine results in serious pathological conditions, such as cretinism, myxedema, and goiter. Its fundamental action in the tissues appears to result in an increase in the oxidative processes. (W. f. 110.)

PITUITARY BODY. This endocrine gland is a composite structure found on the ventral surface of the mid-brain. It consists partly of nerve tissue from the INFUNDIBULUM, originally derived from the fore-brain, and partly of an ectodermal ingrowth, the HYPOPHYSIS, from the dorsal wall of the anterior end of the alimentary canal. In Man an enlargement of the pituitary results in an increase in the size of various tissues, particularly bone tissue of the limbs and face — a disease known as ACROMEGALY. In the Frog there is experimental evidence that the hormone of the pituitary body has a regulatory effect upon the thyroid gland. (W. fs. 140, C; 142.)

ADRENAL BODIES. The pair of ADRENALS in the Frog has been previously noted, one lying on the ventral surface of each of the kidneys. In the higher Vertebrates they are small rounded bodies situated near the kidneys. The hormone secreted by these glands is known as ADRENIN, and among other things it acts on certain nerve endings which, in turn, bring about a contraction of the muscles of the walls of the blood vessels. Thus it may be used in stopping a hemorrhage or to cause an increase in the blood pressure. (W. f. 132.)

COMBINATION GLANDS. It is worthy of note that a number of

important glands with ducts also form hormones and other substances which are passed directly into the blood stream. The LIVER, for example, gives off bile which passes through the hepatic ducts into the intestine, but the liver also secretes urea and sugar directly into the blood stream. Again, the PANCREAS secretes through its duct certain important digestive enzymes into the intestine, but the pancreas also secretes a hormone, INSULIN, into the blood, which influences the sugar metabolism of the body. Diabetes in Man is due to a lack of insulin. It has recently been artificially isolated from the pancreas of various animals and is now being used in the treatment of diabetes. Finally, the gonads — both ovaries and testes — secrete certain hormones directly into the blood which have a very specific action, particularly on the development of certain structural features which serve to characterize the two sexes.

7. *Nervous System*

We now come to a consideration of the vertebrate nervous system. Previous discussions of the nervous system in various Invertebrates have emphasized the paramount importance of this specialized irritable tissue for the reception of environmental and organic stimuli and for the proper coördination of the various parts of the organism in response to stimuli received. These basic functions are, of course, common to the vertebrate nervous system and, in addition, the higher functions of memory and intelligence come more and more into prominence and reach their climax in the Primates. (W. pp. 198–217.)

The nervous system of the Frog can be separated into the following components: (i) CENTRAL NERVOUS SYSTEM. This consists of the BRAIN and SPINAL CORD. The latter lies dorsal to the alimentary tract in a special cavity, the NEURAL CANAL, of the vertebral column. (ii) PERIPHERAL NERVOUS SYSTEM. This consists of the paired CRANIAL and SPINAL NERVES which arise in the central nervous system and run to all parts of the body. (iii) AUTONOMIC, or SYMPATHETIC, NERVOUS SYSTEM. This consists primarily of a pair of ganglionated cords lying close to the dorsal body wall. (iv) SENSE ORGANS. These are the specialized end organs of the peripheral nervous system, adapted for receiving various types of stimuli from the external environment. (W. fs. 107, 142.)

I. CENTRAL NERVOUS SYSTEM

The central nervous system arises early in the development of the embryo by the definite infolding of a portion of the ectoderm of the dorsal body wall to form a hollow NEURAL TUBE which runs practically the entire length of the body. When first formed the neural tube shows very little differentiation, but in a short time the anterior end becomes enlarged and modified to form three divisions, known as the FORE-BRAIN, MID-BRAIN, and HIND-BRAIN. From these the entire brain of the adult Frog is formed. The remainder of the neural tube posterior to the brain retains throughout life a considerable degree of its early character and becomes the SPINAL CORD of the adult. (W. fs. 140; 174, K.)

A. The Brain. Consideration may now be given to the external structure of the fully-developed Frog's brain as seen from the dorsal surface. The extreme anterior end consists of the fused OLFACTORY LOBES. A pair of OLFACTORY NERVES which innervate the olfactory sense organs can be traced anteriorly from this region. Posteriorly, the olfactory lobes merge into a pair of elongated bodies, the CEREBRAL HEMISPHERES, which together constitute the CEREBRUM. Posterior to the cerebrum is an unpaired structure, known as the DIENCEPHALON, which bears the PINEAL BODY. The parts of the brain so far enumerated develop from the fore-brain. Just back of the diencephalon is a pair of OPTIC LOBES which constitute the part of the mid-brain seen from the dorsal surface. Lying posterior and in close proximity to the optic lobes is a transverse ridge of tissue which constitutes the CEREBELLUM. Just back of the cerebellum is the MEDULLA OBLONGATA which appears as a somewhat enlarged portion of the anterior end of the spinal cord. The latter continues posteriorly through the body without further marked differentiation. The cerebellum and the medulla develop from the hind-brain. (W. f. 141, B.)

When viewed from the ventral aspect, the brain shows some additional structural features. Beginning again at the anterior end, it will be noted that the olfactory lobes are not so completely fused as on the dorsal side. Lying posterior to the cerebral hemispheres in the median line are the heart-shaped infundibulum and, just behind it, the hypophysis which together form the pituitary body. The portion of the brain lying ventral to the optic lobes

and on which the infundibulum lies is known as the **CRURA CEREBRI**. The pair of large optic nerves, which innervate the retina of the eye, arise in the diencephalon and then continue ventrally and anteriorly a short distance. The two nerves meet in the mid-ventral line where they cross each other, thus forming the **OPTIC CHIASMA** underneath which the infundibulum lies. The crossing of the optic nerves, so that the fibers from the right side of the diencephalon supply the left eye and vice versa, is a noteworthy feature of the optic nerves in the Vertebrates. (W. f. 142.)

One of the characteristic features of the vertebrate central nervous system is the fact that it is hollow. The central cavity when first formed is quite large, but gradually the walls of the central nervous system thicken and most of the original cavity is thus obliterated, leaving only a small **CENTRAL CANAL** which persists in the spinal cord throughout life. In the brain the anterior end of the central canal is connected with a series of cavities (**VENTRICLES**) which in turn communicate with each other through definite openings (**FORAMINA**).¹

The ventricles and the foramina arise as modifications of the embryonic central cavity of this region of the central nervous system. The ventricles may be seen to good advantage in longitudinal sections through the brain in either a vertical (**SAGITTAL**) or a horizontal (**FRONTAL**) plane. If, for example, a frontal section through the brain is studied, the ventricles will be seen as paired structures. The first pair of ventricles (**LATERAL VENTRICLES**) form the cavities of the cerebral hemispheres and extend anteriorly into the olfactory lobes. The **LATERAL VENTRICLES** are connected near the posterior end of the cerebral hemispheres by the transverse **FORAMEN OF MONRO** which communicates with the unpaired **THIRD VENTRICLE** lying in the diencephalon. An **OPTIC VENTRICLE** is present in each of the optic lobes. These communicate with each other, also anteriorly with the third ventricle, and posteriorly with the single large **FOURTH VENTRICLE** which lies in the medulla. The fourth ventricle decreases in size posteriorly and merges into the central canal of the spinal cord. (W. f. 140, A, B, C.)

The brain of the higher Vertebrates is characterized structurally by a great increase in the size of the cerebral hemispheres so that they overshadow the other parts. This increasing dominance of the cerebral hemispheres reaches its culmination in the Mammals,

¹ Singular, foramen.

and particularly in Man. The study of the brain of the Cat or of the Sheep gives a good idea of the structure of the mammalian brain. (W. f. 141, E.)

B. The Spinal Cord. The study of a section of spinal cord shows it to be roughly circular in outline, but with a considerable dorso-ventral flattening. It is covered by two membranes: an outer, the DURA MATER, and an inner, the PIA MATER. The spinal cord proper consists of an outer portion, the WHITE MATTER, which is composed largely of medullated nerve fibers running in a direction parallel to the cord, and a central portion, the GRAY MATTER. In the layer of white matter there are two clefts; one on the dorsal side of the cord (DORSAL FISSURE) and one on the ventral side of the cord (VENTRAL FISSURE) which is somewhat deeper. (W. f. 143.)

The gray matter, which is surrounded by the white matter, really forms the greater portion of the cord. It extends both dorsally and ventrally into the white matter in such a way that it forms a pair of DORSAL, and a pair of VENTRAL, HORNS. In the center of the gray matter and, therefore, in the center of the cord, is the CENTRAL CANAL lined by epithelial cells. The gray matter contains great numbers of nerve cells, or neurons, with long processes, the nerve fibers. The latter extend into the white matter of the spinal cord and, finally, into one of the connecting spinal nerves as indicated on page 213.

II. PERIPHERAL NERVOUS SYSTEM

A. Cranial Nerves. There are ten pairs of cranial nerves in the Frog which arise from various regions of the brain as follows.

1. *Olfactory Nerves.* These arise in the olfactory lobes. They pass anteriorly and somewhat laterally and innervate the olfactory sensory cells lining the nasal chambers. (W. f. 142, *Ol.*)

2. *Optic Nerves.* These arise in the diencephalon of the brain and then form the OPTIC CHIASMA which has been noted above. From the chiasma one nerve runs to the retina of each eye and innervates the sensory cells there. (W. f. 142, *Op.*)

3. *Oculomotor Nerves.* These arise from the ventral wall of the mid-brain. They run to the eyes where they innervate certain eye muscles and other parts of the eye as well.

4. *Trochlearis Nerves.* These arise posterior to the optic lobes on the dorsal side of the brain and run to the eyes where they innervate one pair of the eye muscles.

5. *Trigeminal Nerves*. This is a large and important pair of cranial nerves. Each trigeminal nerve arises by two roots from the side and near the anterior end of the medulla. The two roots unite to form a PROÖTIC ganglion from which arises the TRIGEMINAL NERVE proper. Each proötic ganglion marks the origin also of an AUTONOMIC NERVE TRUNK. Each trigeminal nerve soon branches into two parts: (a) the OPHTHALMIC and (b) the MAXILLO-MANDIBULAR. The latter divides again into two branches: (i) the SUPERIOR MAXILLARIS and (ii) the MANDIBULAR. The various branches of the trigeminal nerves innervate considerable portions of the facial region, more particularly around the mouth, the tongue, and the muscles of the lower jaw. (W. f. 142, Vg.)

6. *Abducens Nerves*. This pair arises from the ventral side of the medulla, close to and on either side of the mid-ventral line. Each nerve is distributed to certain muscles of the eye and also connects with a proötic ganglion.

7. *Facial Nerves*. This pair arises from the medulla just posterior to the trigeminal nerves. Each facial nerve divides into two main branches: (a) the PALATINE and (b) the HYOMANDIBULAR. This nerve has a wide distribution to various parts of the face, nose, and throat. Each also connects with a proötic ganglion.

8. *Auditory Nerves*. These arise from the medulla just posterior to the facial (7) and run laterally on either side to innervate the inner ear.

9. *Glossopharyngeal Nerves*. These arise from the medulla posterior to the auditory (8) and together with the fibers of the VAGUS (10). They innervate certain muscles and lining membranes of the tongue and pharynx.

10. *Vagus Nerves*. These arise, as has been noted, in common with the glossopharyngeal (9). Each of the vagus nerves has two branches, the anterior one (RAMUS AURICULARIS) being much smaller. It runs forward and is distributed to the region of the tympanum of the ear. The main branch of the vagus runs posteriorly and gives off a number of small branches which innervate the muscles of the shoulder. The remainder of the posterior branch of this nerve is distributed to some of the important visceral organs, such as the esophagus, stomach, lungs, and heart. (W. f. 142, Xg.)

In the higher Vertebrates, two other pairs of cranial nerves are present: the SPINAL ACCESSORY (11) and the HYPOGLOSSAL (12),

which are distributed to the muscles of the shoulder, neck, and tongue.

B. Spinal Nerves. There are ten pairs of spinal nerves in the Frog, all of which arise in the spinal cord and are distributed to various regions of the body. In the higher Vertebrates there is a considerable increase in the number of pairs of spinal nerves. Thus, in Man, there are 31 pairs. In all the Vertebrates, however, the structure of the spinal nerves is essentially the same. Each spinal nerve arises in the spinal cord by a DORSAL and a VENTRAL root. The two roots unite a short distance from the cord to form a single nerve composed, therefore, of both dorsal and ventral elements. On the dorsal root, just before its union with the ventral root, there is a swelling known as the DORSAL GANGLION. The dorsal roots are known as the SENSORY, or AFFERENT, roots. Accordingly the nerve fibers of which they are composed are connected with sensory nerve cells in the skin or other regions, which receive the stimuli. The stimuli incite nerve impulses which are conveyed to the spinal cord by the dorsal root. The ventral roots of the spinal nerves are known as the MOTOR, or EFFERENT, roots. They run from the spinal cord to the peripheral regions where they connect with muscle tissue. The impulse, which has come through the sensory dorsal root, is relayed by the spinal cord to the proper motor ventral root, through which it reaches and stimulates the muscles necessary to bring about the appropriate response. The spinal nerves of the Frog are as follows. (W. fs. 142, 143.)

1. The first pair of spinal nerves arises from the anterior end of the spinal cord just posterior to the medulla and emerges from between the first and second vertebrae. Each of these nerves usually gives off a small branch to the second spinal nerve and then continues in a lateral direction into the muscles of the body wall. (W. f. 142, *Spn. 1.*)

2. This is a large pair of spinal nerves. Each one usually receives a branch from the first nerve and also a branch from the third. The second nerve with these branches forms the BRACHIAL PLEXUS. The important nerves which arise from this plexus supply the muscles of the shoulders and fore limbs. (W. f. 142, *Br.*)

3. The third pair of spinal nerves is small, and each, after giving off a branch to the brachial plexus as noted, can be traced laterally into the musculature of the body wall. (W. f. 142, *Br.*)

- 4, 5, and 6. These three pairs of small nerves, which arise from the

spinal cord near the center of the abdomen, are distributed to the muscles of the body wall in the abdominal region. (W. f. 142, *Sp.* 4.)

7, 8, and 9. These three pairs of large spinal nerves run posteriorly and laterally and soon anastomose on each side of the body to form a large and important SCIATIC PLEXUS, from which arises the SCIATIC NERVE that innervates each hind leg. The seventh spinal nerve, anterior to the plexus, gives off a small nerve which is distributed to the abdominal muscles. The sciatic nerves can be traced into the legs. Numerous branches are given off which innervate the various leg muscles. (W. f. 142, *Js.*)

10. This pair arises near the posterior end of the spinal cord. The tenth nerve usually receives a small branch from the ninth, and together they form a small plexus which chiefly innervates parts of the urogenital system. An eleventh pair of spinal nerves is occasionally found which, when present, joins this plexus.

C. Histology of Nerve Tissue. The microscopic study of nerve tissue shows that it is composed of highly specialized NERVE CELLS, or NEURONS. The neurons are structurally distinctive in that each cell body possesses a long process, termed the AXON, and one or more shorter irregular processes, termed the DENDRITES. The dendrites convey impulses to the cell, while the axon conveys impulses away from the cell. A nerve consists of a large number of axons bound together by connective tissue elements. Each of the axons in a nerve, if traced to its source, will be found to have its origin in the cell body of a single neuron which may be located a considerable distance from the peripheral end of the nerve. The cell bodies are not found indiscriminately placed along the nerves, but, in general, they are grouped in the central nervous system and in ganglia such as those present on the dorsal roots of the spinal nerves. (W. fs. 7; 32, *F*; 138.)

A microscopic examination of a section through a nerve shows that its method of construction may be compared in a general way to that found in a telephone cable. Covering the nerve is a connective tissue sheath, the PERINEURIUM, from which strands of connective tissue are given off. These strands divide the nerve into a number of compartments, the FUNICULI, each of which encloses a great many microscopic nerve fibers, or axons. Carrying the analysis further, each of the axons is found to have a thin connective tissue sheath, the NEURILEMMA. Lying between the outer neurilemma and the enclosed axon is a comparatively heavy sheath

of fatty tissue, the MEDULLARY SHEATH. Each axon in this cable-like nerve is thus separated, or as we might say, insulated, from all the other nerve elements by the medullary sheath and neurilemma, and all the elements in a nerve are bound together by the connective tissue fibers which are continuous with the outer perineurium. A nerve fiber, such as just described, is known as the MEDULLATED type in distinction from the NON-MEDULLATED type, frequently found in the autonomic nervous system, in which the medullary sheath is lacking. (W. f. 138, *D.*)

III. AUTONOMIC NERVOUS SYSTEM

There are two main nerve trunks in this division of the nervous system which lie dorsally in the coelom, one on either side of the spinal column. Each trunk originates in the head region in a proötic ganglion which, as stated, is formed by the fifth, sixth, and seventh cranial nerves, and may be regarded as a chain of ganglia. The ganglia receive one or more branches (RAMUS COMMUNICANS) from each of the spinal nerves shortly after it emerges between the vertebrae. (W. f. 142, *Sg. 1, 10.*)

Branches from the autonomic system innervate various important organs of the body. In the anterior part of the body these branches innervate the muscular walls of the subclavian and occipito-vertebral arteries, as well as the anterior ends of the oviducts. Farther posteriorly, a number of branches form a very important nerve center, the SOLAR PLEXUS, from which nerves are distributed to the important abdominal organs including the stomach, intestine, liver, pancreas, and parts of the urogenital organs. Still farther posteriorly, branches from this system form the UROGENITAL PLEXUS which innervates various urogenital organs. The autonomic nervous system is responsible for the involuntary control of many of the most important organs of the body, acting largely through the medium of the unstriated muscle tissue.

IV. SENSE ORGANS

The sense organs are composed of ESSENTIAL and ACCESSORY parts. The essential part of a sense organ consists of peripheral sensory cells which are capable of receiving one or more types of stimuli from the external environment. Accessory structures are also generally present in sense organs, which aid in various ways in bringing the stimulus to the nerve tissue. For example, the

lens of the eye is an accessory structure which focusses the light rays on the sensitive cells of the retina.

A. Contact Stimulus or Sense of Touch. The sense of touch is located in the skin. Scattered through the skin there are specialized sensory end organs, known as TACTILE CORPUSCLES, which lie just under the epidermis. These tactile corpuscles consist of a small group of flattened cells, in close connection with which are tiny nerve endings which respond to contact stimuli; other sensory areas in the skin are sensitive to heat, cold, pain, etc.

B. The Chemical Sense. The skin of the Frog as a whole is sensitive to chemical stimuli. If, for example, a drop of weak acid is placed on the skin of any region it will stimulate sensory cells there present, and the animal will endeavor to wipe off the acid. However, the chemical sense is best developed in the mouth and in the olfactory organs. The sense of taste is primarily a chemical one, and there are many groups of specialized sense cells scattered over the surface of the tongue and also, more or less generally, over the entire lining of the mouth. The taste organs consist of epithelial cells together with elongated sensory cells. Each of the latter is connected by fine processes with a nerve. The various chemical substances in the food stimulate, or excite, these sensory cells, and the impulses thus set up are received by the central nervous system over the connecting nerve fibers. (W. f. 146, B.)

The sense of smell located in the nasal cavity is also a chemical sense. The air which is drawn into the nasal cavity through the external nostrils comes in contact with sensory cells which line this region. These cells are extremely sensitive to very minute quantities of chemical substances present in the air. A microscopic study of the tissue lining this cavity shows that this inner membrane is made up of a basal connective tissue portion and an outer layer of OLFACTORY EPITHELIUM. The latter contains three types of cells, the OLFACTORY, BASAL, and INTERSTITIAL. The olfactory cells are the true sensory cells. They are greatly elongated, and at the outer free end of each, which forms a portion of the lining of the nasal cavity, there are a number of fine protoplasmic processes. These structures, in some way, are influenced by the chemical substances present in the air, and the resulting impulses are passed to the connecting nerve. (W. f. 146, A.)

C. The Sense of Hearing and of Position. The ear is a sense organ which is adapted for receiving two types of stimuli; those of

sound and those of position, or equilibrium. In the higher Vertebrates, the ear consists of three parts: (1) the OUTER EAR, which is modified for collecting the sound waves; (2) the MIDDLE EAR, which receives the waves thus collected and conveys them to (3) the INNER EAR, which is the essential part and contains the nerve tissue. In the Frog, however, the outer ear is lacking, and the sound waves come first into contact with the tympanic membrane. (W. f. 148.)

Considering, first, the structure of the MIDDLE EAR, it should be noted that it is an accessory structure by which the sounds are conveyed from the external environment to the inner, essential sensory tissue of the ear. The middle ear of the Frog, which lies near the outer surface of the body, begins with the tympanic membrane, as noted above. The latter forms the closing membrane of a tube which constitutes the cavity of the middle ear, and which communicates with the mouth cavity by means of the EUSTACHIAN TUBE. The openings of the Eustachian tubes in the mouth have been previously noted. The tympanic membrane is of such a nature that the impinging sound waves cause it to vibrate, and these tympanic vibrations are then conveyed through the cavity of the middle ear and into the inner ear by a rod, the COLUMELLA, one end of which is attached to the tympanic membrane, and the other end to a portion of the inner ear. In the higher Vertebrates, the columella is replaced by three bones in the middle ear, which are termed, in accordance with their shape, the MALLEUS, INCUS, and STAPES, or commonly, the hammer, anvil, and stirrup. Collectively they constitute the AUDITORY OSSICLES.

The INNER EAR lies in a specialized bony cavity of the skull, known as the AUDITORY CAPSULE, and is surrounded by the liquid PERILYMPH which fills the auditory capsule. The inner ear consists of a very complicated structure, known as the MEMBRANOUS LABYRINTH, which contains the essential sensory tissue. The membranous labyrinth is composed of a large upper portion, the UTRICULUS, which is concerned with the sense of position, and a small portion lying below, the SACCULUS, which is concerned with the sense of hearing. The sacculus has an irregular, bag-like shape, is filled with a fluid known as the ENDOLYMPH, and contains the nerve endings. The vibrations of the columella cause vibrations in the endolymph and these, in some way, influence the sensory cells. The impulses thus received are conveyed to the brain by

the auditory nerves (eighth cranial) and thereby give rise to the auditory sensations. (W. f. 147.)

The utricle, in which the sense of position is located, consists of a basal part attached to the sacculus, and bears three SEMI-CIRCULAR CANALS which lie primarily at right angles to each other. The utricle also contains ENDOLYMPH surrounding the sensory nerve cells. Movements in the endolymph stimulate the sensory cells and thus bring about a sense of position. Experimental work has shown clearly that when the labyrinth with the semicircular canals is removed from both sides of the head, the Frog is not able to regulate its position at all. If the labyrinth is destroyed on only one side an asymmetrical attitude of the Frog results; the head being tipped one way or the other depending upon which side has been operated on.

In the higher Vertebrates, including Man, a greatly coiled structure, known as the COCHLEA, develops from the sacculus. It is regarded as a derivative of the sacculus of the ear in the lower Vertebrates. The cochlea becomes the essential part of the ear for the function of hearing. It contains an extremely complex structure, known as the ORGAN OF CORTI, in which the nerve endings are located. The vibrations of the auditory ossicles are communicated to the endolymph present in the cochlea and in the rest of the membranous labyrinth at a certain region of the vestibule known as the OVAL FORAMEN. (W. f. 148.)

D. The Sense of Sight. The eyes, which have as their specific function the reception of light, or photic, stimuli, lie in special cavities, or ORBITS, on the dorsal and lateral wall of the head. The eye is spherical in shape, and is composed of several layers of tissue. It is covered on the outside by a strong, connective tissue sheath, known as the SCLEROTIC COAT, which forms a continuous covering of the eye, except for one small area in the posterior region where it is pierced by the optic nerve running from the eye to the brain. Posteriorly, the sclerotic coat of the eye is opaque, but in the front there is a transparent region, known as the CORNEA, through which the light rays can pass into the interior of the eye. (W. f. 150.)

Attached to the sclerotic coat are several eye muscles which move the eye in various directions. In the first place, there is a large RETRACTOR BULBI muscle attached to the posterior portion of the eyeball. When this muscle contracts the eye is drawn back into the orbit. The eye is protruded from the orbit by the contraction

of the **LEVATOR BULBI** muscle which lies obliquely along the ventral part of the orbit.¹ The other muscles are (1) a pair, the **SUPERIOR** and **INFERIOR RECTI**, which rolls the eye up or down; (2) a pair, the **ANTERIOR** and **POSTERIOR RECTI**, which rolls the eye to the right or left, and (3) a pair, the **SUPERIOR** and **INFERIOR OBLIQUE** muscles, which gives the eye oblique movements.

Lying within the sclerotic layer is the thin **CHOROID LAYER**. It contains many blood vessels, is deeply pigmented, and, anteriorly, forms the colored portion of the eye, or **IRIS**, in the center of which is a circular opening, the **PUPIL**. The iris also contains muscular elements, and in its functioning may be compared to the iris diaphragm in a camera. When there is not enough light the **RADIATING MUSCLES** in the iris contract, thus enlarging the pupillary opening, through which light is admitted to the interior of the eye. In bright light, the **CIRCULAR MUSCLES** of the iris contract and this results in a constriction of the pupillary opening so that only a small amount of light is admitted to the sensitive portions of the eye.

The innermost layer of the eye is the **RETINA**. This contains the sensory cells which are adapted for receiving the photic stimuli and passing them on to the optic nerve. The retina lines the greater part of the eyeball, but does not extend to the anterior surface as do the other two layers. It consists of (a) a thin outer layer containing pigmented cells, which lies next to the choroid coat of the eye and (b) a thicker sensitive layer containing the nerve tissue, which forms the inner lining of most of the eye cavity. The sensitive layer of the retina is an extremely complex structure, and a microscopic study of properly prepared material shows that it is composed of no less than nine layers of tissue, the last of which is the sensory tissue composed of very highly specialized cells showing two structural types, the **RODS** and the **CONES**. The former are more numerous and appear as narrow, elongated bodies with distinct striations. The rods also show a differentiation into a larger and a smaller type. The cones are considerably larger but not so elongated as the rods. (W. fs. 150, 151.)

The optic nerve enters the retina posteriorly. It passes through the retinal layers giving off fine branches which run to all portions of the retina and, finally, innervate the essential rod and cone cells. The part of the retina where the optic nerve enters lacks these

¹ The two muscles just described are not present in the human eye.

light-receiving elements, and is designated as the **BLIND SPOT**. Just to one side of the blind spot is the region of the retina (**FOVEA CENTRALIS**) where the vision is most acute. (W. f. 150.)

Having now considered the three separate layers which form the wall of the eyeball, mention should next be made of an important accessory structure, the **CRYSTALLINE LENS**, which lies anteriorly. The lens serves to focus the light rays on the retina. It is enclosed in a membrane to which the **CILIARY MUSCLES**, located near the base of the iris, are attached. These muscles act in such a way as to alter the convexity of the lens so that either near or far objects may be brought to a focus. The small cavity of the eyeball lying between the iris and the lens is known as the **POSTERIOR CHAMBER** and the larger cavity lying between the iris and the cornea is known as the **ANTERIOR CHAMBER**. Both of these cavities are filled with a watery, transparent fluid, known as the **AQUEOUS HUMOR**. Back of the lens is the **VITREOUS CHAMBER** which is the largest chamber of the eye, and contains a semisolid, transparent substance, the **VITREOUS HUMOR**.

V. FUNCTIONS OF THE NERVOUS SYSTEM

In considering the functions of the various parts of the nervous system it is to be noted that the brain is regarded as the main directing center of the body. In it myriads of adjustments are consummated which are necessary in arranging for the correct responses to all types of stimuli. In a general way, it can be stated that the spinal cord is dominant to the peripheral regions of the nervous system; that the brain is dominant to the spinal cord, and that the cerebral hemispheres at the anterior end of the brain are the chief dominating and directing agencies of the nervous system as a whole and therefore of the entire body. Furthermore, if the Frog can be said to possess the power of purposive thinking, or intelligence, it is located in the cerebral hemispheres.

However, experimental work involving the complete removal of the cerebral hemispheres of the Frog has shown that such an animal can continue to live and carry on most of the functions in a normal manner except that a certain amount of spontaneity is lacking. Although it is known that the chief coördinating centers of the Frog's brain lie in the optic lobes, it can be shown experimentally that the brain may be completely extirpated as far back as the medulla, and the animal will recover and be able to carry

on a number of regularly coördinated movements. It is clear, therefore, that such actions do not necessarily involve the anterior parts of the brain. Responses of this type which do not involve the higher parts of the brain are known as REFLEX ACTIONS. The hind-brain and the anterior end of the spinal cord are particularly adapted for the more involved types of reflex action. There are many reflex actions of a lower grade which are located even farther posteriorly in the spinal cord.

Good examples of reflex actions may be seen in many of our own reactions. If, for example, a finger touches a hot surface it is immediately jerked away. This is a reflex action and as such does not involve definite thought on our part. In such an action the impulse from the sensory cells in the skin enters the central nervous system through the dorsal root of a spinal nerve. In the spinal cord the impulse is relayed to the proper motor cells and, leaving the spinal cord through a ventral root, reaches the connecting muscles and incites the appropriate response. Or, in learning to walk, each step involves thought, but after a time the actions become largely reflex in their nature, and the higher brain centers are thereby freed for other more important functions. Thus it is with many other similar actions which are first acquired by conscious effort. (W. f. 143.)

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XVI. VERTEBRATE DEVELOPMENT

A. DEVELOPMENT OF THE FROG

THE Frog's egg when observed with the naked eye appears as a tiny sphere composed of a dark-colored portion, termed the ANIMAL POLE, and a light-colored portion, termed the VEGETAL POLE. Each egg is enclosed in a transparent vitelline membrane around which are the layers of jelly. A microscopic study of prepared sections shows that the protoplasm of the egg is largely concentrated in the animal pole. This fact is emphasized by the unusual position of the nucleus which lies approximately in the center of the animal pole. The vegetal pole contains a large proportion of non-living food material, or YOLK, for the use of the embryo during the early stages of development before it is able to take in food from the external world. (W. pp. 238-267.)

1. *Fertilization*

The sperm and the eggs of the Frog are both discharged directly into the water. The former by their active swimming movements reach the eggs and FERTILIZATION takes place. It is probable that the sperm are attracted by certain chemical substances given off by the eggs. In fertilization the nucleus of the egg and the nucleus of the sperm unite in the egg cell to form the synkaryon just as has been noted previously in the Invertebrates. If the eggs are not fertilized no development takes place, and disintegration begins after they have been in the water for a while. When an egg has been fertilized the synkaryon prepares at once for mitotic cell division. A typical spindle is formed, and the egg soon divides into equal halves which remain enclosed within the vitelline membrane.

2. *Early Development*

CLEAVAGE. In general, the animal pole of the Frog's egg divides more rapidly than the vegetal pole. The latter is retarded by the large proportion of inert food substances, or yolk, which are present in it. The early cleavages generally occur in a regular order which may be described as follows.



FIGURE 12

A reproduction of the famous frontispiece from Harvey's *De Generatione Animalium*, published in 1651. Zeus is here shown liberating all types of animals from the egg. Note the inscription "*Ex ovo omnia*" on the egg shell.

(1) The first plane of cleavage begins near the center of the animal pole and extends down through the vegetal pole, thus cutting the egg into two equal sized cells, each composed of a portion of both the animal and vegetal poles. (W. f. 174, A.)

(2) The second cleavage is at right angles to the first, but in the same direction, so that the embryo now consists of four similar cells, each composed of material from both poles. (W. f. 174, B.)

(3) The plane of the third cleavage is at right angles to the first and second. It cuts the quadrants, previously formed, in the region which separates the animal pole from the vegetal pole. The resulting eight cells consist of an upper quartet of small, dark-colored cells formed from the animal pole, and a lower quartet of large cells formed from the vegetal pole. (W. f. 174, C.)

(4) The fourth and fifth cleavages are parallel to the first and second, but between them. They both begin in the animal pole and slowly extend through the vegetal pole.

(5) The sixth cleavage is parallel to the third, but lies above it and is, therefore, entirely in the animal pole.

(6) After the sixth cleavage the divisions become more or less irregular. As a result of the more rapid division of the dark-colored cells of the animal pole, they are much smaller after a time than those of the vegetal pole. (W. f. 174, D.)

BLASTULA. At about the 24-cell stage definite indications are found of an internal cavity, termed the **SEGMENTATION CAVITY**, or **BLASTOCOEL**, situated well toward the animal pole of the egg. As cleavage continues, this segmentation cavity, as shown by a study of prepared sections, increases in size. It is enclosed above and on the sides by layers of the dark cells, and, in the same way, below by the larger white cells. Such a stage constitutes the **BLASTULA** of the Frog's egg, and it has the general external appearance of a golf ball with approximately one-half of the surface (animal pole) blackened. (W. f. 174, D, E, F.)

GASTRULA. Typically a **GASTRULA** is a two-layered sac which develops from the one-layered blastula by invagination of a portion of the outer ectoderm to form an inner endoderm layer. In the Frog, however, owing to the large amount of yolk stored in the vegetal pole, the invagination of the ectoderm is considerably modified, and the two-layered gastrula stage is reached partly by an overgrowth and partly by an invagination of the dark ectoderm cells. The comparatively rapid growth and division of the dark

cells results in an actual covering up of the light-colored cells of the vegetal pole so that as the process proceeds, the area of the vegetal pole as seen externally constantly diminishes, until finally only a tiny portion, the YOLK PLUG, remains. (W. f. 174, G.)

Coincident with the overgrowth there is a turning under, or invagination, of the outer dark ectoderm cells to form the two-layered gastrula. This process begins in a small area (GRAY CRES-CENT) lying near the boundary between the dark and white cells. The area of invagination soon becomes circular in outline, and then, as the growth over the white cells continues, contracts in diameter, finally reaching the stage noted above, where only a tiny area of the white cells, the yolk plug, is visible externally. The circular area of invagination is known as the BLASTOPORE. It indicates the posterior end of the embryo and the approximate position of the future ANAL OPENING. (W. f. 174, I.)

Inside the embryo at this stage, a considerable amount of ENDO-DERM has formed near the blastopore. It is thickest on the dorsal side but spreads laterally, soon forming a definite layer beneath the ectoderm. It obliterates the original blastocoel and a new endo-dermal-lined cavity is formed, which constitutes the primitive alimentary canal, or ENTERON, of the embryo. It terminates posteriorly at the blastopore which, as mentioned above, marks approximately the position of the permanent anal opening. The MOUTH OPENING is later formed at the opposite end of the developing embryo. During gastrulation the MESODERM is also forming in the region of the blastopore as a layer between the ectoderm and endoderm. The ectoderm, endoderm, and mesoderm constitute the PRIMARY GERM LAYERS from which all the tissues and organs of the Frog develop. (W. f. 174, H.)

During the process of invagination, a median longitudinal strip of cells lying above the enteron begins to differentiate and to become separated from the mesoderm. From it an axial rod of tissue, the NOTOCHORD, develops. This is the forerunner of the segmented, bony VERTEBRAL COLUMN which later develops around the notochord. An external examination of an egg at about this stage, when the blastopore is nearly closed, shows a differentiation of the ectoderm on the dorsal side of the body to form the MEDULLARY PLATE which is the forerunner of the CENTRAL NERVOUS SYSTEM. The edges of the medullary plate, on either side of the median line of the embryo, become enlarged and somewhat ele-

vated to form the MEDULLARY FOLDS. A little later the two folds, running almost the length of the body, meet above the NEURAL GROOVE in the midline and fuse, and thus a dorsal NEURAL TUBE of ectoderm is formed. From this ectodermal neural tube the differentiated brain and spinal cord later develop. (W. f. 174, I.)

3. *Later Development*

Synchronously with the formation of the central nervous system from the ectoderm, as just described, the embryo begins to lose the spherical shape of the original egg and to elongate in an antero-posterior axis so that the definite body regions can be identified. Anteriorly the HEAD is indicated, and just back of it on each side of the body, the ectoderm becomes thickened and modified to form the elevated GILL ARCHES through which lateral openings into the pharynx (GILL SLITS) later appear. Anterior to the gill region, a swelling can be seen on the side of the head, which is the beginning of certain sense organs. The ventral and posterior regions of the body are still very heavily loaded with yolk material at this time. Projecting from the extreme posterior end, on the dorsal side of the embryo, is the TAIL BUD which grows posteriorly to form the tail region. A depression on the anterior ventral surface of the head indicates the position of the future MOUTH, and a similar depression at the posterior end of the body, near the original blastopore, marks the future position of the ANUS. Just posterior to the mouth depression, a crescent-shaped area indicates the VENTRAL SUCKER. During all the changes thus far, the animal is not feeding, but is getting its nourishment from the utilization of the food materials which were stored in the vegetal pole of the egg. (W. f. 174, J.)

The microscopic examination of a longitudinal section, in a sagittal plane, through an embryo in the 'tail-bud' stage shows the following condition. There is an outer covering of ectoderm cells. Lying ventral to the ectoderm, on the dorsal side, is the neural tube, just formed by the fusion of a portion of the dorsal ectoderm. The neural tube runs the entire length of the embryonic body and, at this stage, shows very little differentiation. At the anterior end of the embryo it curves ventrally, and the closed end lies in the ventral half of the body. The curved, anterior end of this tube differentiates into the fore-brain and the mid-brain. The hind-brain develops from the region of the neural tube lying just posterior.

At the posterior end of the body the neural tube also bends ventrally, and in that region its cavity connects for a time through the NEURENTERIC CANAL with the cavity of the enteron. (W. f. 174, K.)

Lying ventral to the neural tube is the solid rod-like notochord, and lying below this the enteron, the walls of which are composed of endodermal cells. The enteron runs the entire length of the body. In the head region the cavity of the enteron is very much larger than it is posteriorly and this enlarged portion constitutes the primitive PHARYNX. Various portions of the alimentary canal differentiate from it later. A projection of the pharynx runs posteriorly under the yolk mass, close to the ventral body wall. The LIVER is formed from this diverticulum, and it is consequently known as the LIVER DIVERTICULUM. Anterior to this, between the ventral wall of the pharynx and the body wall, is a space which contains a few scattered embryonic mesoderm cells. These cells represent the rudiment of the future HEART.

Back of the pharynx, the enteron continues as an undifferentiated tube to the posterior end of the body, where it communicates, as noted above, with the cavity of the neural tube. At this time the permanent anal opening has not been formed, but a little later it breaks through the body wall, just below the embryonic blastopore, and the temporary connection with the neural tube is also lost. A considerable mass of yolk material is present in the embryo at this stage. The cells containing this material are largely grouped in the posterior half of the embryo, between the ventral wall of the enteron and the ventral wall of the embryo. By the time this food has been utilized, the mouth and anal openings have been formed and the embryo can begin to feed.

Lying on either side of the neural tube and notochord, in a somewhat triangular space bounded externally by the ectoderm, is the mesodermal tissue. The mesoderm is first formed as two sheets of tissue running anteriorly from the blastopore, one on either side of the neural tube and notochord. They grow laterally and ventrally, and soon become separated by a longitudinal division into a dorsal portion (VERTEBRAL PLATE) and a ventral portion (LATERAL PLATE). The vertebral plates soon show evidence of segmentation, and divide transversely into a number of muscle segments, or MYOTOMES. The lateral plates of mesoderm grow ventrally and extend around the ventral half of the embryo until they meet and

fuse in the mid-ventral line, thus forming a complete layer of mesoderm, just under the ectoderm and enclosing the endoderm. Before this process has been completed, each lateral plate splits into an outer layer, known as the SOMATIC LAYER, which is closely applied to the ectoderm of the body wall, and an inner layer, the SPLANCHNIC LAYER, which encloses the endoderm of the enteron, and later gives rise to the supporting and muscular elements of the wall of the alimentary canal. Between the somatic layer and splanchnic layer a cavity develops which is the permanent body cavity, or COELOM.¹

Rapid growth of the embryo continues, and in a few days after fertilization a free-swimming, fish-like tadpole has developed with definite HEAD, TRUNK, and TAIL. By this time the embryo has hatched; that is, it has emerged from the capsule of jelly enclosing it. The enteron has developed into a long, coiled INTESTINE which is typical of herbivorous animals. External respiratory organs are present in the form of branched GILLS which arise from each side of the head. These persist only a very short time and are replaced by INTERNAL GILLS lying in the gill slits which open into the pharynx. Definite sense organs (eye, nose, and ear) can be identified in the head region. The tail has grown posteriorly to a considerable length. Along each side of the body the primitive muscle segments, myotomes, as noted, can be seen lying inside the outer ectodermal covering. Limbs are not present at this time. (W. f. 175.)

4. *Derivation of the Organs*

As already noted, all the tissues and organs of the Frog develop from the three primary germ layers. The tissues derived from the ECTODERM include the epidermis which forms the outer covering over the entire body, also the central nervous system with all of its later development.

The ENDODERM gives rise to the original wall of the primitive enteron, and these cells remain as the permanent lining of the alimentary canal so that, even in the adult condition, the alimentary canal is lined for almost its entire length by cells which have been derived from the endoderm. There is a portion of the mouth cavity (STOMODAEUM) where the ectoderm is slightly invaginated,

¹ This development of the coelom is essentially the same as in the Earthworm which is illustrated in W. f. 173, J, K.

and also a region at the extreme posterior end (PROCTODAEUM) of the alimentary canal where the same condition prevails. In addition to lining the alimentary canal, the endoderm cells also form a number of organs which develop originally as outgrowths from the alimentary canal. These associated organs all form in much the same way by an outpocketing of the endodermal wall of the enteron to form either single or paired structures which later differentiate into various important organs, such as the LUNGS, THYROID GLANDS, LIVER, PANCREAS, and BLADDER. (W. fs. 110; 174, K.)

From the important MESODERM layer are formed the MUSCULAR, VASCULAR, and CONNECTIVE TISSUES of the body. Previous mention has been made of the division of the mesoderm into the vertebral and lateral plates. The myotomes of the former, together with the somatic layer of the lateral plates, give rise to the muscle tissue of the body wall and appendages, together with the connective tissues, vascular elements, etc.; while the muscle layers, and other elements of the wall of the alimentary canal, except the endodermal lining, are derived from the splanchnic layer. The coelom is lined with PERITONEUM which is continuous over the alimentary canal and other organs. Both the somatic and splanchnic layers contribute to the formation of the peritoneum. From it arise the MESENTERIES by which various organs are attached to, and suspended from, the walls of the coelom. The mesoderm also gives rise, for the most part, to the urogenital system. (W. f. 95, B.)

The fact should be emphasized that the organs, in general, are not formed from a single tissue, but on the contrary represent a mosaic of various tissues. The liver, for example, is fundamentally an endodermal organ, but not exclusively so, for it contains vascular, connective, and nervous elements derived from both the mesoderm and ectoderm.

5. *Metamorphosis*

After a period of time, the length of which shows a great deal of variation among different species of Frogs, the fish-like larva, or TADPOLE, undergoes radical changes both in structure and habits. These changes constitute a process of METAMORPHOSIS, and result in the formation of an air-breathing, adult Frog with two pairs of limbs and no tail. Experimental work in recent years has shown that the process of metamorphosis in the Frog is controlled to a

great extent by the hormone secreted by the thyroid gland. The chief changes which occur during metamorphosis may now be noted:

(a) In the development of limbs, a swelling appears on either side of the body at the base of the tail. These are the posterior LIMB BUDS, and they continue to grow rapidly and soon form the hind limbs. The fore limbs, which develop later, are formed from tissues of the body wall in the gill region. If the gill covering is cut away in this region at the proper time, the tiny fore limbs may be found beneath; one on either side. Before metamorphosis is completed the fore limbs break through the operculum, so that at this stage we have a tadpole with two pairs of limbs and also with a long tail. (W. f. 175, *F-J*.)

(b) Shortly after the appearance of the fore limbs, the tail begins to decrease in size, and this process continues until, by the time metamorphosis is completed, it is entirely resorbed. It is not clear as to just how these degenerative changes in the tissues of the tail are brought about. (W. f. 175, *K*.)

(c) During metamorphosis, great changes take place in the alimentary canal. In the tadpole, this structure is very long and coiled and without much differentiation between the various regions. Such a type of alimentary tract is adapted for securing nourishment from plant tissues which form the greater part of the food of the tadpole. The metamorphic changes cause a great decrease in the length of the tract, and a greater degree of differentiation between the various regions. These structural changes adapt the alimentary canal for the digestion of animal tissues which form the greater part of the food of the adult Frog.

(d) During metamorphosis the lungs, which started to develop very early in the embryonic life and then stopped, begin their growth anew and form a pair of elongated, distensible, tubular sacs with highly vascularized walls. They lie, as we know, in the anterior end of the coelom and are connected by the trachea with the glottis which opens in the ventral wall of the mouth. Coincident with the development and functioning of the lungs, the internal gills begin to degenerate, and the young Frog is no longer able to secure oxygen from the water, but must come to the surface and inhale air directly into the lungs, so that the cells and plasma of the blood can carry on the respiratory interchange. These metamorphic changes having been completed, the transformed tadpole

is like the adult, except that it is smaller. It feeds and gradually attains the sexually-mature, adult condition. (W. f. 175, L.)

6. *Life Processes in the Frog Embryo*

When an egg is fertilized by a sperm, it is then an embryo of a new generation; in other words, an independent organism, and as such it must carry on the essential life processes if it is to survive. It will be of value briefly to indicate how the Frog embryo is able to do this. In the first place, the question of nutrition must be considered. The process of cell division and all the other developmental phenomena require energy. This energy in the early stages, and until the time when the alimentary tract is completed by the mouth and anal openings, is obtained by utilizing the yolk material present in the vegetal pole, which is supplied to all the cells.

From the one-celled condition until sometime after the tail-bud stage, the embryo does not possess a vascular system. Inasmuch as food material is scattered among the cells there is no general problem with regard to the transportation of food. The greater portion, however, is concentrated near the middle of the embryo, ventral to the enteron and posterior to the pharynx. Apparently excess food in this region is passed on to the other cells of the embryo just as in *Hydra* and other animals where no vascular system ever develops.

Soon after the embryo has hatched from the egg jelly it begins to swim vigorously, and later when the alimentary tract is completed, the animal begins to ingest food. It is adapted for plant feeding, but the tadpole will eat animal tissue when available. It is aided in feeding by a special organ, the VENTRAL SUCKER, just posterior to the mouth. This enables the tadpole to remain attached to a plant in the water and to rasp the plant tissues with horny projections on the jaws.

Respiration must, of course, be continuous from the earliest stages. At first this respiratory interchange takes place at the surface of the embryo, through the jelly capsule. This method does not long suffice, and coincident with the establishment of the vascular system, gills are formed through which the interchange of gases takes place. External gills are present for a few days. Later they are covered by a fold of ectoderm (OPERCULUM), and internal gills develop in the walls of the gill slits. In this condi-

tion, water is drawn into the mouth and forced out through the lateral gill slits in the wall of the pharynx, where it comes into contact with the gill filaments. This fish-like method of breathing is continued until the lungs are developed, after which the animal secures oxygen from the air. The gills on the right side of the embryo degenerate first.

Excretion of urea in the tadpole is carried on in the early larval stages by tubular organs, known as the PRONEPHROI. A pair of these is developed very early, one on either side of the body. Each pronephros consists of three tubules which open into the coelom at one end. They unite at the other end to form the common PRONEPHRIC DUCT which runs posteriorly on each side of the body and empties into the cloaca. (W. f. 129.)

The anterior portion of each pronephric duct degenerates in later larval life, and another group of tubules develops posteriorly on each side of the body, which becomes connected with the vascular system. These form the permanent kidneys, or MESONEPHROI, of the Frog which open into the posterior part of the former pronephric ducts. The latter remain as the permanent ducts. In the higher Vertebrates, the permanent kidneys develop later and are known as the METANEPHROI.

B. DEVELOPMENT OF THE CHICK

The male and female reproductive organs of the Birds have the same fundamental type of structure that is found in the Frog and other Vertebrate animals. They are paired structures in their early development, but in the later stages the ovary and associated structures on the right side of the female undergo degeneration so that the functional reproductive organs in the female are present only on the left side.

The OVARY, as seen with the naked eye, consists of a mass of various-sized eggs which appear as yellowish globules. The ovary is suspended from the dorsal wall of the abdomen by a connective tissue mesentery, known as the MESOVARIIUM. Lying near the ovary is a large, glandular OVIDUCT which ends anteriorly, as in the Frog, in a large ciliated opening, the OSTIUM, and connects posteriorly with the cloaca. The oviduct consists of three portions: (1) the OSTIUM, which is followed by (2) a GLANDULAR PORTION, the cellular walls of which secrete both the 'white' of the egg and the shell; and (3) a THIN-WALLED PORTION, which opens into the cloaca.

The portion of the Hen's egg corresponding to an entire Frog's egg is the so-called yolk. In the early stages of development in the ovary, the egg cells are typical in size and shape. During the developmental stages a considerable amount of food material is assimilated by each of these cells which are to develop into mature eggs, so that they rapidly increase in size. There is a certain rhythm in egg formation. The Hen usually lays an egg a day for some two or three weeks, and then will stop for a period during which the CLUTCH of eggs can be incubated. This may then be followed by another period of egg laying. (W. f. 169.)

The large amount of food material present in the egg crowds the protoplasm to the surface of one pole, where it can be seen in a mature egg as a tiny, white, circular area, the BLASTODERM. The remainder of the cell outside of this small blastoderm consists chiefly of inert food material. This condition is an exaggeration of that found in the Frog's egg, where the greater proportion of the protoplasm is at the animal pole and the greater proportion of food material is at the vegetal pole. At this stage the egg cell, or, as it is commonly termed, 'the yolk,' bursts forth from the ovary, is taken into the ostium, and begins its passage to the exterior through the oviduct. Normally, in the upper end of the oviduct, the egg cell comes in contact with the sperm, and fertilization occurs, after which cell division begins. The blastoderm of the Hen's egg is the only part of the cell that divides. Thus we have partial, or MERO-BLASTIC, cleavage in the Hen's egg as compared with total, or HOLO-BLASTIC, cleavage in the Frog's egg. Another type of meroblastic cleavage was earlier noted in the Arthropod egg. (W. f. 169.)

The fertilized egg continues its passage down the oviduct, and the cells in the anterior glandular portion of the oviduct secrete several layers of ALBUMEN, or 'white,' around it; a portion of which, lying in contact with the vitelline membrane surrounding the egg, form the CHALAZAE. These make it possible for the embryo to maintain a definite orientation during development. Farther posterior other secreting cells form two thin, enclosing membranes which lie just within the shell. Still farther down the oviduct other secreting cells give off a material which hardens to form the outer EGG SHELL. The passage through the oviduct usually takes 24 hours, so that if the egg is fertilized in the anterior end of the oviduct, it has reached the 24-hour stage of development at the time it is laid. When the egg is laid, development ceases

unless the proper temperature (38°C.) is again supplied. The embryo of the egg will remain dormant without injury to the embryonic cells for several days and then start to develop again when given the proper temperature.

The division of the blastoderm in the Hen's egg after fertilization results in the formation of a great number of irregularly shaped cells which lie near the center of the blastoderm. These are the primitive ectoderm cells, and they soon form a few layers of cells which overlie a small cavity on the surface of the yolk, which is the **BLASTOCOEL**. This constitutes the blastula stage of the Chick embryo, and it consists of flattened layers of ectoderm cells above the blastocoel rather than a sphere of cells enclosing this cavity as in the Frog. (W. fs. 31, 174.)

The ectoderm cells continue to divide, and very soon, in the region which is to become the posterior end of the embryo, they begin the formation of the gastrula with ectoderm and endoderm. The two layers extend anteriorly and laterally, and in a short time cover most of the blastodermic area. A median thickening appears in the blastoderm at about the eighteenth hour of incubation, which is known as the **PRIMITIVE STREAK**, and indicates the longitudinal axis of the animal. The ectoderm and endoderm are in contact along the primitive streak, and it is also in this region that the mesoderm layer arises. The first mesoderm cells are given off in the posterior part of the primitive streak, but they soon spread laterally and anteriorly, forming a definite third layer between the ectoderm and endoderm.

At the anterior end of the primitive streak, the ectoderm cells divide very rapidly, and a definite anterior thickening can soon be observed in this region, known as the **HEAD PROCESS**. It consists at first of only the ectoderm and endoderm layers, but later the mesoderm is also drawn into it. The region of the blastoderm in which the head process forms, *i.e.*, just anterior to the primitive streak, contains the rudiments of the body of the future embryo. Very shortly there is an anteroposterior thickening of the dorsal ectoderm in this region to form the beginning of the **CENTRAL NERVOUS SYSTEM**. This corresponds to the medullary plate stage in the Frog, and similarly there is an elevation of the lateral edges of the medullary plate and a fusion in the mid-line to form the **NEURAL TUBE**. Lying below it will be found the endodermal **NOTOCHORD**. The lateral mesoderm segments into the **MYOTOMES**, which, as in

the Frog, differentiate into dorsal and lateral portions. The latter splits into the outer SOMATIC LAYER and inner SPLANCHNIC LAYER between which is the COELOM.

All this time the Chick embryo, developing in the area of the blastoderm, is lying flat on the surface of the yolk. There now begins, at about the twentieth hour of incubation, a process of folding, first at the anterior end (HEAD FOLD), later at the sides (LATERAL FOLDS), and then posteriorly (TAIL FOLD), which results in an almost complete separation of the embryo from the YOLK SAC, so that the latter after a time is attached to the embryo only by the YOLK STALK, through which the food material is transported to the young embryo by the embryonic VASCULAR SYSTEM.

One of the distinctive features of the development of the Chick as compared with the Frog is that, owing to the position of the blastoderm which is spread out flat upon the surface of the yolk, the rudiments of the various structures such as the coelom, heart, alimentary canal, etc., are formed in right and left halves on either side of the main body of the embryo. These are located in the outlying or, as they are termed, EXTRA-EMBRYONIC REGIONS of the blastoderm. The process of folding off the embryo from the underlying yolk, which has been noted above, brings the right and left rudiments of these organs together underneath the embryo, where they unite in the mid-ventral line to form the complete organs.

By the end of the third day of incubation, the embryo has grown to a considerable size, and many of the organs are well-established. At this stage the entire animal is covered by an EMBRYONIC MEMBRANE, the AMNION, which, starting anterior to the embryo in the ectoderm, has grown back over the animal from the anterior end and also to some extent from the posterior end, with the result that the embryo is enclosed in a definite sac (AMNIOTIC CAVITY). At this stage of incubation, the embryo does not have a straight, antero-posterior axis, but the head end has a bend (CERVICAL FLEXURE) of almost 90 degrees toward the right. The central nervous system is well-developed, together with the sense organs such as the eye, nose, and ear. The vascular system is also well-established and functioning. The heart at this time consists of an auricle and ventricle. The auricle receives the blood, containing food material, which has come in from the yolk sac through the large vitelline veins. This blood passes into the ventricle, and then it is forced out through the arteries to all parts of the growing body, and

eventually back to the yolk sac. The embryo, at this stage, has four pairs of gill slits which are similar in structure to those which develop in the aquatic Vertebrates. In the Chick, however, the gills never function and, after a few days, the gill slits disappear. (W. f. 235.)

The Chick embryo continues to develop, receiving its food from the yolk and carrying on the respiratory interchange through the surface of the shell. The Hen's egg requires about 21 days of incubation, and then the Chick breaks through the shell with the aid of a specialized structure which develops on the beak, and comes forth as an active animal able to secure its nourishment, and thus to continue its growth until the adult condition is reached.

C. THE DEVELOPMENT OF THE MAMMAL

The Prototheria, such as the Duck-bill and Echidna, constitute the lowest group of the Mammals. It is noteworthy that in this group of Mammals the females are OVIPAROUS, that is, they lay eggs which develop outside the body and are similar to the large-yolked eggs of the Birds and Reptiles. In the Prototheria, however, the young animals do not at once begin an independent existence when they hatch from the egg but are nourished for a time by secretions from the mammary glands of the mother. (W. pp. 191-195; 271-273.)

In the Metatheria and Eutheria the females are VIVIPAROUS, that is, the fertilized eggs are retained within the body of the female in a specialized portion of the oviducts, known as the UTERUS, until the embryos have reached a certain stage of development, at which time they are, as we say, BORN. The degree of development of the embryo at birth varies a great deal in the different species. In the metatherian mammals, such as the Kangaroo and the Opossum, the young are born in such an immature and helpless condition that it is necessary for the mother to carry them for a time after birth in a special sac, the MARSUPIUM, which is present on the ventral abdominal wall of the female. Here the embryos are nourished by milk from the mammary glands until they reach a sufficient degree of maturity to take care of themselves. Even among the eutherian mammals the development of the embryo at birth shows great variation in the different classes. Thus the new-born embryo is very well-developed among the hoofed Mammals, or Ungulates, while among the Primates

the young are born in a comparatively helpless and immature condition. (W. f. 134, *a, d, g.*)

Except in the Prototheria, the mammalian egg, quite unlike that of the Frog and Hen, is very small, being in general microscopic in size, and containing practically no stored food for the nourishment of the embryo during the early stages of development. It is therefore necessary, in order for development to proceed, that the fertilized egg receive nourishment from the maternal tissues very soon after development begins. This is supplied as described below. (W. f. 133.)

If sperm are present the egg is fertilized soon after it enters the oviduct, and begins to divide. The cleavage is holoblastic and soon results in the formation of a spherical body of cells, known as a MORULA, which may be regarded as similar to the blastula stage. Except for the complete cleavage, the early development of the mammalian egg, including the formation of the various organs, shows great similarity to that of the Chick. A particularly noteworthy feature of the mammalian embryo at this stage is the very early formation of the PRIMARY GERM LAYERS and the EMBRYONIC MEMBRANES such as the amnion. A study of the internal structure of the embryo at the morula stage shows that the cells are differentiated into an INNER CELL MASS, which contains the rudiments of the embryonic body proper, and an outer layer, known as the TROPHOBLAST, which develops from the ectoderm at the surface and encloses the entire embryo. (W. f. 176.)

During the cleavage stages the embryo is passing through the oviducts down into the uterus, where it is to be attached and retained for a time during development. By the time it reaches the uterus the outer covering of trophoblast has been formed. This layer is very essential to the developing embryo, for the cells of which it is composed are able to secrete a ferment which erodes the small portion of maternal tissue lining the uterus with which the tiny embryo is in contact. Thus the embryo attaches itself to the mother, becoming actually embedded in the uterine wall. Nutritive materials are temporarily secured by the digestive and absorptive action of the trophoblast. A little later, by a combination of trophoblastic tissues of the embryo with maternal tissues in the uterine wall, a very remarkable mammalian structure, known as the PLACENTA, is formed which connects the embryo with the maternal tissues and through which it is nourished. Leading

from the placenta is the embryonic UMBILICAL CORD which is directly attached to the body of the embryo. (W. f. 134, *b, h, i.*)

The placenta is the organ by means of which the essential interchange of materials between the embryo and the mother takes place. Certain large arteries of the mother bring maternal blood, carrying nutritive materials and oxygen, to the placenta, where it flows into large open sinuses. Here the maternal blood bathes the finger-like projections, or VILLI, formed from fetal tissue. The fetal villi contain the endings of the fetal blood vessels which run through the UMBILICAL CORD and connect with the vascular system of the embryo. One of the fetal vessels (UMBILICAL ARTERY) brings blood to the placenta from the embryo. This blood contains nitrogenous wastes and carbon dioxide given off by the embryo. During the passage through the capillary network in the placenta these wastes are given off through the walls of the villi and pass into the maternal blood. Synchronously, nutritive materials and oxygen are received from the maternal blood. The embryonic blood, now freed from the wastes and containing the substances necessary for the embryo, passes into the UMBILICAL VEINS, which carry it away from the placenta and back to the embryo through the umbilical cord. It should be emphasized that the vascular systems of the mother and embryo are not directly connected in the placenta or elsewhere. All interchange of materials between the mother and the developing embryo in the uterus must, therefore, take place by diffusion through the embryonic tissues in the placenta.

The period of development within the uterus, which is termed GESTATION, varies greatly in the different Mammals. Thus in the Mouse the normal period of gestation is 20 days, while in Man it is approximately 280 days. When the mammalian embryo has completed the necessary development within the uterus, BIRTH occurs. This is largely brought about by powerful rhythmic contractions of the involuntary muscle tissue present in the walls of the uterus. The final result of the contractions is the complete separation of the embryo and the fetal tissues from the maternal tissues, and the passage of the embryo to the exterior, where an independent existence is begun.

REFERENCES

Consult the list given for the previous chapter (p. 221).

PART II
LABORATORY DIRECTIONS

I am impressed with the fact that the greatest thing a human soul ever does in the world is to see something, and tell what it saw in a plain way. Hundreds of people can talk for one who can think, but thousands can think for one who can see.

— *Emerson.*

The invention of the microscope made small things seem large, and revealed to sight what was too small to be seen without it; but the use of magnifying glasses brought an advantage with it of a different kind — it taught those who used them to see scientifically and exactly. In arming the eye with these increased powers the attention was concentrated on definite points in the object; what was seen was to some extent indistinct, and always only a small part of the whole object; perception by means of the optic nerve had to be accompanied by conscious and intense reflection, in order to make the object, which is observed in part only with the magnifying glass, clear to the mental eye in all the relations of the parts to one another and to the whole. Thus the eye armed with the microscope became itself a scientific instrument, which no longer hurried lightly over the object, but was subjected to severe discipline by the mind of the observer and kept to methodical work. The philosopher Christian Wolff observed very truly in 1721, that an object once seen with the microscope can often be distinguished afterwards with the naked eye, and this, which is the experience of every microscopist, is sufficient evidence of the effect of the instrument in educating and training the eye.

— *Sachs*

INTRODUCTION

A. EQUIPMENT¹

Each student will require the following equipment for his laboratory work :

- (1) Text-books.
- (2) Loose-leaf notebook, about $8\frac{1}{2} \times 10\frac{3}{4}$ inches, with white drawing paper.
- (3) Dissecting instruments consisting of medium-sized scalpel, small sharp-pointed scissors, medium sharp-pointed scissors, fine forceps, two dissecting needles in holders, pipet, and ruler.
- (4) Two drawing pencils (2H and 4H) and an eraser.
- (5) Compound microscope with two eyepieces and two objectives.
- (6) Dissecting microscope with one lens.
- (7) Six glass slides.
- (8) Twelve cover glasses.
- (9) Lens paper.
- (10) Filter paper.
- (11) Piece of absorbent gauze.
- (12) Pins.

B. THE USE AND CARE OF THE COMPOUND MICROSCOPE

1. The compound microscope is a delicate, complicated, and expensive instrument and must always be handled with great care. Each day before using the microscope, see that all parts are clean. Be sure that they are kept clean during the exercise and that the instrument is clean when you leave. If you find the instrument dirty or in bad order, report it at once to the instructor in charge of the room. Lens paper is furnished for cleaning the lenses, and it is not permissible to clean the lenses with any other material.

2. The microscope consists of the following parts, each of which should be identified :

- (a) The BASE and UPRIGHT SUPPORT.
- (b) The STAGE, with a CENTRAL OPENING which contains an IRIS DIAPHRAGM for regulating the amount of light. A CONDENSER is also present on some instruments.

¹ The instructor will indicate which items in the equipment are to be supplied by the student.

- (c) The MIRROR, with concave and plane surfaces, which is attached underneath the stage.
- (d) The BODY, with COARSE and FINE ADJUSTMENTS for focussing, DRAW TUBE, EYEPIECE, or OCULAR, and revolving NOSE-PIECE holding the OBJECTIVES.

Learn how each of these parts is used.

3. Place the microscope in position, with the upright support toward you. See that the low-power eyepiece No.¹ and the low-power objective No.¹ are in position and that the iris diaphragm is open. Adjust the mirror so that the maximum amount of light will be reflected up through the central opening of the stage. In general, use the mirror with the concave surface up.

4. Place the glass slide, on which the object to be examined is mounted, upon the stage with the object directly over the central opening. Carefully turn the coarse adjustment screw away from you until the end of the objective is approximately one-fourth of an inch from the upper surface of the slide. Then, while looking through the eyepiece, slowly turn the coarse adjustment screw toward you until the object comes into view. Bring the image into an exact focus by slowly turning the fine adjustment screw in either direction, as may be necessary. Never focus downward with the coarse adjustment while looking through the microscope. It is less tiring and better in every way to keep both eyes open while looking through the microscope. You will be able to do this with a little practice.

5. Always find an object first with the lowest magnification, as described in the preceding paragraph, and always use the lowest magnification possible to accomplish the work in hand. Before changing from a lower to a higher power, always see that the object is exactly in the center of the field. The magnification may then be increased as desired in the following ways:

- (a) By replacing low-power eyepiece No.¹ with high-power eyepiece No.¹
- (b) By replacing low-power objective No.¹ with high-power objective No.¹ This is accomplished by revolving the nose-piece. Inasmuch as this objective, when in focus, is very close to the upper surface of the preparation, it will be necessary to use great care in making this change.
- (c) By doing both (a) and (b).
- (d) The magnification can be still further increased in some microscopes by extending the draw tube, but this method is rarely used.

¹ The numbers are different in the various makes of microscopes. The correct numbers for your microscope will be supplied by the instructor.

The approximate magnifications afforded by the various combinations are as follows:

Eyepiece ¹	×	Objective ¹	=	diameters magnification.
"	×	"	=	" "
"	×	"	=	" "
"	×	"	=	" "

When a very low magnification is desired, as for example in the study of a large opaque object, the simple DISSECTING MICROSCOPE is used. It gives a magnification of about 10 diameters.

6. At the close of each exercise be sure to remove the slide that you have been studying from the stage of the microscope. Examine the microscope carefully and make sure that all parts, including the lenses, are perfectly clean and then return the microscope to its proper place in the case. Remember that since there are others who must use the same microscope, the welfare of the laboratory depends upon your coöperation in keeping the apparatus in order.

C. MICROSCOPIC PREPARATIONS

7. The preparations which will be examined with the compound microscope may be divided into two classes as follows:

(1) PERMANENT PREPARATIONS in which the material to be examined has been previously subjected to complicated histological methods for preserving, staining, and permanent mounting on a glass slide. Great care must be observed in handling these preparations. A charge will be made for breakage.

(2) TEMPORARY PREPARATIONS which you will make when necessary by mounting the material to be examined on a glass slide according to the following directions:

- (a) Thoroughly clean a glass slide and cover glass.
- (b) Place a small drop of water in the center of the glass slide.
- (c) Place the object to be examined in the drop of water.
- (d) Cover the drop of water containing the object with the cover glass.
- (e) Remove any superfluous water remaining around the cover glass with the absorbent filter paper. Be sure that no water gets on to the upper surface of the cover glass. The preparation is now ready to be studied under the microscope.
- (f) When you have finished your study of a temporary preparation, clean the slide and cover glass, and replace them in the drawer for future use.

D. LABORATORY DRAWINGS

8. It is essential that careful attention be paid to the following rules for laboratory drawings:

¹ Numbers will be supplied by the instructor.

- (a) Draw on only one side of the paper, using a well-sharpened drawing pencil.
- (b) Arrange the drawings as neatly and evenly on the page as possible, giving each plenty of space.
- (c) Leave at least one inch margin around the edges of the sheet.
- (d) Always LABEL every drawing and each of its parts.
- (e) Remember particularly that accuracy and neatness are two of the most important factors in good laboratory work.
- (f) See that the laboratory room number, the seat number, and your name and class are placed on the upper right-hand corner of each sheet of drawings.
- (g) The drawings should be placed in a loose-leaf notebook. The direction sheets in this manual are *perforated along the left edge* so that, if desired, one can be removed for each exercise and mounted in the loose-leaf notebook opposite the sheet with the day's drawings.

PRELIMINARY MICROSCOPIC WORK ¹

A. DISSECTING MICROSCOPE

1. Examine, with the dissecting microscope, a slide on which a printed word has been permanently mounted. What apparent movement results when the slide is moved to the right? To the left? When it is moved toward, and away from you? When it is rotated?

B. COMPOUND MICROSCOPE

2. After having carefully studied the previous section on "The Use and Care of the Compound Microscope," examine, with the lowest power of the compound microscope, a letter from the preparation you have been studying. What apparent movement results when the slide is moved to the right? To the left? When it is moved toward and away from you? When it is rotated? See that the position of the slide is such that the letter is in normal reading position, and then draw the letter in its apparent position and magnification as seen through the microscope.

3. Replace the low-power eyepiece No.² with the high-power eyepiece No.² . Draw the letter.

4. Replace the high-power eyepiece No. ² with the low-power eyepiece No.² and, by revolving the nosepiece, replace the low-power objective No.² with the high-power objective No.² . Carefully refocus with the fine adjustment. Draw the letter.

5. Without disturbing the objectives replace the low-power eyepiece with the high-power eyepiece. Draw the letter.

6. In some microscopes the magnification can be still further increased by extending the draw tube. Extend it to its full length and, after refocusing, note the effect on the magnification.

7. Examine, with the low power, a preparation of scales from the wing of a Moth or Butterfly. Make several outline drawings showing different types of scales.

8. Examine, with the high power, and study the markings on the surface of the scales and make a drawing of a portion of a scale to show their character.

9. Mount and make a microscopic examination of various tiny objects which are readily available. These may include particles of dust; fibers of hair, cotton, silk, etc.; air bubbles in water; and globules of oil in a mixture, or emulsion, of oil and water.

¹ B. pp. 241-244.

² Instructor will supply information.

CELLULAR ORGANIZATION OF PROTOPLASM¹

A. PLANT TISSUES

1. Carefully peel off a small piece of the delicate, transparent covering (EPIDERMIS) from the upper surface of a green leaf. This can be done by using the point of the scalpel or by tearing the leaf. Mount the epidermis according to the directions for temporary preparations given in the previous section on "Microscopic Preparations" (p. 243).

2. Examine the epidermis in the TEMPORARY PREPARATION just made with both the low and the high power of the microscope. Draw about ten adjacent EPIDERMIS CELLS to show their arrangement and general structure. Each cell should be drawn about one-half inch in diameter.

3. Examine, with the low power, a PERMANENT PREPARATION of stained sections of an Onion root. Note that some of the sections have been cut parallel to the long axis of the root (LONGITUDINAL SECTIONS), and some of the sections have been cut across, *i.e.*, at right angles to, the long axis (TRANSVERSE, OR CROSS, SECTIONS).

4. Study first one of the longitudinal sections under the low power. Draw in outline a portion of the section near the tip of the root. Study the cells in this region with the high power. Note: (a) the CELL WALL which marks the cell boundary; (b) the rather faintly stained CYTOPLASM which forms the cell body; (c) the central, spherical NUCLEUS embedded in the cytoplasm and frequently containing (d) a tiny NUCLEOLUS. Many of the older cells, situated some distance back from the tip of the root, contain (e) a large VACUOLE which, when the cell is alive, is filled with a liquid, (f) the CELL SAP.

5. Make (a) a drawing of a portion of the longitudinal section, lying near the tip, under the low power to show the general arrangement of the cells; (b) a drawing of a single cell under the high power to show the detailed cell structure.

6. Study one of the transverse sections under the low power. Select a typical cell and make a drawing of it under high power similar to the one just made in paragraph 5.

7. Compare the last two drawings of cells in paragraphs 5 and 6. With them as a basis make an outline drawing of a cell in perspective, that is, one which will show the cell as a solid with the three dimensions.

¹ B. pp. 3-8.

CELLULAR ORGANIZATION OF PROTOPLASM¹

B. ANIMAL TISSUES

1. Mount a small piece of the shed outer layer (EPIDERMIS) of Frog skin, which has previously been stained. Note that the general structure of these animal cells is the same as that of the plant cells. Identify CELL WALL, CYTOPLASM, and NUCLEUS. Remember that each cell is entirely enclosed in a cell wall through which you are viewing the cytoplasm and nucleus. Examine the preparation, with both the low and the high power, and draw about 10 adjacent cells to show their structure and arrangement.

2. With the end of the handle of the scalpel or your finger *gently* scrape the inside of your cheek. Mount the scrapings and examine the preparation with both the low and the high power. You should find numerous irregular shaped cells which have been detached from the lining. Draw, under high power, several cells of different shapes.

3. Carefully remove the cover glass from the preparation you have been studying and stain the cells by adding a drop of acetic carmine. Replace the cover glass, examine under the high power, and observe the changes which have taken place as a result of the stain. It will be noted that the NUCLEI of the cells stain more heavily than the CYTOPLASM. Make a drawing, about one inch in diameter, of a single cell showing the general structure as observed.

4. Examine a permanent preparation of the skin of the Frog or of some other Vertebrate, and note several layers of epidermal cells on the upper surface. These range in shape from the cuboidal or the columnar type lying below, to the flattened type above which forms the outer surface. Make a drawing of a portion of the epidermis to show the cell structure and arrangement.

5. Mount a drop of Frog's blood which has been diluted with normal salt solution. Examine the preparation under the low power and note the general appearance and structure of the numerous, disc-shaped blood cells (RED CORPUSCLES) floating in the plasma.

6. Examine the preparation with the high power, gently tapping the cover glass from time to time in order to set the cells in motion so that you may see them as solids with their three dimensions. Draw a number of the cells as seen from various aspects.

¹ B. pp. 3-8.

GREEN PLANTS ¹

A. PLEUROCOCCUS

1. Examine, with the dissecting microscope, the greenish material present on the outside surface of a piece of bark and note its general appearance. Scrape off a little of the material and place on a slide. Mount in a drop of water and examine with the low power of the compound microscope. Note that the material consists of great numbers of tiny green, spherical bodies. Each of these is a cell, and each also constitutes the entire plant body of this unicellular plant, *Pleurococcus*.

2. Examine the preparation with the high power. Select a large single cell and note: (a) the CELL WALL, which is quite thick and composed of cellulose, and (b) the large green CHLOROPLASTID, which almost fills the body of the cell and lies embedded in (c) the CYTOPLASM. (d) The NUCLEUS lies near the center of the cell but is usually more or less obscured by the chloroplastid. Stain the preparation with iodine solution and reexamine for the nucleus. Make a drawing of a single cell, about one inch in diameter, to show the structures observed.

B. SPIROGYRA

3. Mount a few filaments of *Spirogyra* and examine with the low and the high power. Note that the filaments consist of cells which are attached end-to-end. Note the CELL WALLS and the connection between adjacent cells. Note also in each cell the green, spiral CHLOROPLASTIDS with the starch-forming bodies (PYRENOIDS).

4. Examine the cell wall carefully and note the thin layer of CYTOPLASM which lines it. Also the large central VACUOLE, filled with CELL SAP, which occupies the greater part of the cell. Focus carefully near the center of the cell and find the NUCLEUS, surrounded by a thin layer of the cytoplasm and suspended by delicate strands of cytoplasm which run out to the peripheral layer lining the cell wall. Draw a few attached cells.

C. ELODEA

5. Mount two or three leaves from near the tip of the stem of the water-living plant, *Elodea*. Examine with the low and high power. Identify the rectangular cells with definite cell wall enclosing the cytoplasm in which numerous green disc-shaped chloroplastids are to be seen. Under favorable conditions a movement of the chloroplastids may be detected. This phenomenon will be studied in a later exercise (B. p. 255). Stain the preparation with a drop of iodine solution and reexamine to find the nucleus. Draw to show the structure as observed.

¹ B. pp. 8-12.

COLORLESS PLANTS, OR FUNGI¹

1. Mount a drop of stagnant water which contains decaying organic material. Study the preparation carefully with the high power and note the various types of Bacteria which are there present. The straight, rod-like forms are *BACILLI*; the corkscrew-like forms are *SPIRILLA*; the extremely small, spherical forms are *COCCI*. Make a drawing of the field under observation, showing all kinds of Bacteria found there.

2. Examine, under the high power, permanent preparations of various kinds of Bacteria and draw a few cells of each kind. For example: (a) *Bacillus subtilis*. This is a very common example of decay bacteria. Note the tiny rectangular cell bodies with definite cell walls, but with no visible differentiation into cytoplasm and nucleus; (b) *Bacillus anthracis*. This is an important spore-forming pathogenic organism. Note that the cells tend to adhere end-to-end to form a filament, or chain. This is due to the action of an outer gelatinous capsule; (c) *Bacillus typhi*. There are usually three species associated which are very similar structurally. They are all very tiny, thick rods which under high power ($\times 500$) appear almost spherical.

3. Examine a flask of water in which some compressed Yeast and sugar have been placed. Note the general characteristics of the fluid, including the smell, color, and taste, and also the minute bubbles of gas which are continually rising to the surface. Connect the flask with rubber tubing so as to conduct the gas which is being generated through clear lime-water. Note the precipitate which gradually forms in the liquid. This shows that the gas is carbon dioxide, which unites with the calcium oxide in solution to form insoluble calcium carbonate.

4. Mount a drop of the liquid from the flask, after stirring a little, and examine with both the low and high power. Note the enormous numbers of tiny oval cells, each one of which is a unicellular YEAST PLANT. Interspersed among the yeast cells are the much larger STARCH GRAINS. Note that many of the yeast cells show various-sized projections, or BUDS. Some of the buds also may again bud before they are detached from the parent cell, and thus TEMPORARY COLONIES are formed. Add a drop or two of iodine solution at one side of the cover glass. Examine the preparation at once under the high power, near where the iodine was placed. Note the staining reaction of the yeast and the starch. The blue color with iodine is a well-known test for starch.

5. Make a large drawing to show the structure of a yeast cell, noting CELL WALL, CYTOPLASM, generally with numerous tiny granules, and the large VACUOLE. The NUCLEAR MATERIAL cannot be distinguished.

¹ B. pp. 12-13.

PROTOPLASMIC MOVEMENT ¹

1. Mount a few drops of water from a laboratory culture containing an abundant supply of several species of free-swimming Protozoa. Examine microscopically first with the low power and then with the high power. Note the vigorous and rapid movement exhibited by various species present, particularly those bearing cilia, such as *Paramecium*. Numerous slower moving species bearing one or more vibrating whip-like processes (FLAGELLA), such as *Euglena* which has one flagellum, may usually be found. More difficult to find as a rule are the smaller amoeboid species such as *Amoeba*, which progress slowly by a flowing movement of the cytoplasm and a consequent formation of irregular PSEUDOPODIA.

2. Place a small piece of the gill of a clam on a slide and with two dissecting needles gently tear the piece of tissue apart in a drop of body fluid. Mount and examine the preparation with high power. Note the currents in the surrounding fluid caused by the rapid vibration of the delicate protoplasmic processes (CILIA) which are present on the outer exposed surfaces of the ciliated cells of the gills.

3. Examine a live Earthworm and note the method of locomotion. Its movements are due to the actions of the muscle tissues in the body wall, coördinated by the nervous system. Slightly irritate various regions of the body and note the response as exhibited by the muscular movements.

4. Note the rhythmical contraction shown by the muscular tissue in the beating heart of a freshly anaesthetized Frog. Note further that the movements still persist when the heart is entirely removed from the body and placed in normal (0.7%) salt solution.

5. Mount two or three young leaves from near the tip of a stem of the common water-living plant, *Elodea*. Examine various regions of the leaves with the high power, particularly along the mid-rib and the edges, and find an area in which a flowing movement of the cytoplasm is to be noted in some of the cells. This will be shown by the movements of the green disc-shaped bodies (CHLOROPLASTIDS) as they are carried around the cell, within the cell wall, by the flow of the cytoplasmic current.

6. To demonstrate the fact that microscopic lifeless particles may also exhibit spontaneous movement, mount a drop of water which contains some powdered carmine in suspension and examine the preparation under the high power. Careful observation will show that the suspended particles are constantly exhibiting an oscillating movement which is believed to be due to the impact of the rapidly moving molecules of the liquid. This is known as Brownian movement.

¹ B. pp. 13-17.

AMOEBA ¹

1. Mount a few drops of water containing numerous large Amoebae. Examine the preparation under a medium power (high-power eyepiece with low-power objective). The animals will be seen as very small, irregular, semi-transparent bodies composed of a jelly-like living material (PROTOPLASM) and generally containing numerous particles of various shapes and colors which give it a granular appearance. When a large Amoeba has been found, move the slide so as to bring the specimen exactly in the center of the field, and then examine under the high power. Be very careful not to lose the specimen when shifting to the high-power objective.

2. Study the specimen and note the absence of any visible cell wall and the almost continual variations in the shape of the body due to the formation of irregular processes (PSEUDOPODIA) from any part of the surface. Note that the animal moves slowly from place to place. Try to explain how this is accomplished. Make a series of outline drawings — at least ten — at one-minute intervals to show the changes in the shape of the Amoeba under observation. Indicate in each drawing, by means of arrows, the direction the animal is moving.

3. Study an Amoeba carefully under the high power and note that there is a differentiation of the protoplasm into (a) an outer transparent layer of ECTOPLASM and (b) an inner granular region of ENDOPLASM. This arrangement can be seen clearly in the pseudopodia. The endoplasm contains (c) the NUCLEUS which usually is seen as a spherical, granular body; (d) numerous GASTRIC VACUOLES in which are various kinds of food materials in the process of digestion; (e) a spherical CONTRACTILE VACUOLE which gradually increases in size as the liquid wastes accumulate until a certain size is reached. Then it suddenly contracts, and discharges the wastes to the exterior. Make a drawing, about 3 inches in length, of an Amoeba to show the detailed structure of this animal.

4. Make careful observations of an Amoeba which is moving actively and note the reaction of the ectoplasm to the various bits of débris with which it comes in contact. If care is taken, it is often possible to observe the manner in which an Amoeba rejects inorganic material with which it comes into contact, ingests food particles, and egests the indigestible refuse.

¹ B. pp. 19-28.

EUGLENA ¹

1. Mount a drop of water containing Euglena, and examine with the low power. The active specimens will be seen as green, elongated, free-swimming organisms. When an individual is not actively swimming, it generally shows certain characteristic squirming movements (EUGLENOID MOVEMENTS) which result in marked changes in the shape of the cell, so that the body may be almost spherical at times.

2. Select a favorable specimen which is exhibiting euglenoid movements and study it carefully under high power. Note the thin cell wall, or PEL-LICLE, which remains unbroken but readily responds to the flowing movements in the cytoplasm. Make a series of ten outline drawings to show the successive changes in the shape of a single individual.

3. Study various specimens of Euglena with the high power. Distinguish the rather blunt ANTERIOR and the finely pointed POSTERIOR ENDS. Note: (a) the FLAGELLUM which is attached in a depression at the anterior end (careful focussing will be necessary); (b) the red pigment spot (STIGMA); (c) the CONTRACTILE VACUOLES and RESERVOIR which are seen as a light-colored area near the stigma; (d) the NUCLEUS.

4. The green color of Euglena is due to CHLOROPHYLL which is present in numerous disc-shaped CHLOROPLASTIDS quite uniformly distributed through the cytoplasm. Other larger bodies (PYRENOIDS) can be noted in some species, which are regarded as starch-forming centers.

5. Make a drawing about 3 inches long showing all the observed structures.

6. Occasionally, dormant individuals may be found which are almost spherical in shape and surrounded by a rather thick CYST WALL. Study any such encysted specimens present in your preparation and make drawings to show the structure as observed.

7. Mount and examine a few drops of water from a laboratory culture containing various other common species of Flagellates, such as Monads, Peranema, Phacus, etc. Identify the various species present and compare their general structure and activities with those of Euglena. (W. f. 23.)

¹ B. pp. 29-33.

VOLVOX ¹

1. Place a drop of water containing Volvox on a slide. Examine, *without cover glass*, under the low power. Each Volvox colony will be seen as a more or less transparent, hollow sphere. Note that each colony is composed of a large number of tiny, greenish bodies (SOMATIC CELLS) which are embedded in a supporting intercellular material. In many cases a number of smaller spheres are enclosed within the transparent walls of the parent colony. These are the DAUGHTER COLONIES, and they have arisen by repeated divisions of asexual reproductive cells (PARTHENOGENIDIA) which develop without fertilization. Make an enlarged drawing of a Volvox colony to show the structure as observed.

2. Carefully place a cover glass on the preparation and examine with the high power. Focus carefully on the wall of a colony and study the somatic cells. Note that the cell body of each consists of an irregular-shaped, greenish-colored bit of cytoplasm. Branching out from each cell body are very fine cytoplasmic strands which run through the intercellular material and connect with adjacent cells so that there is a protoplasmic continuity throughout the colony. Each cell also possesses two flagella which project to the exterior and aid in the movements of the colony. Draw a portion of the wall of the colony giving a view of the cells as outlined above.

3. Focus on one of the enclosed asexual daughter colonies. Note the comparatively small amount of intercellular material between the cells of a young colony as compared with the parent colony. Draw a portion of the wall of the daughter colony.

4. If material is available, study a Volvox colony in which germ cells are present. In such a colony note (a) a SPERMARY, which consists of a large number of SPERM CELLS or MALE GAMETES, grouped together to form a rather flat plate, and (b) an OVARY of about the same size as the spermary, but which contains only a single EGG CELL, or FEMALE GAMETE. Both the spermaries and ovaries are embedded in the wall of the colony. Draw to show the structure as observed.

¹ B. pp. 34-38.

PARAMECIUM ¹

1. Mount a drop of water containing *Paramecia*, together with a little powdered carmine, and examine with the low power. The animals will be seen as light-colored, rapidly-moving bodies which rotate on their long axis as they swim. With the naked eye, the *Paramecia* are just barely visible as tiny white specks.

2. Select a quiet animal under the low power and then study with the high power.² Distinguish the ANTERIOR and POSTERIOR ends. Note: (a) the clear outer ECTOPLASM with PELLICLE; (b) the granular, inner ENDOPLASM; (c) the fine, vibratile CILIA which cover the entire body; (d) the depression (PERISTOME) which begins at the anterior end and extends obliquely backward to beyond the middle of the body; (e) the MOUTH, located near the posterior end of the peristome; (f) the funnel-like depression (GULLET) which leads from the mouth down into the endoplasm; (g) the position and rhythmic appearance and disappearance of the two CONTRACTILE VACUOLES with their RADIATING CANALS. Focus carefully on the edge of the body and note (h) the layer of tiny oval bodies (TRICHOCYSTS) lying in the ectoplasm just beneath the outer surface.

3. Observe that the current caused by the ciliary action sweeps the carmine particles, which were placed in the drop of water, down the peristome, through the mouth opening and into the gullet, at the lower end of which they collect in a GASTRIC VACUOLE. Note the numerous gastric vacuoles containing the carmine particles in the endoplasm.

4. Make a drawing about 3 inches long showing the structures observed.

5. Remove the cover glass of the preparation you have been studying and add a drop or two of acetic carmine. This will kill the animals and also stain the nuclear apparatus (MACRONUCLEUS and MICRONUCLEUS). Study with the high power and add the details of nuclear structure to your drawing in paragraph 4.

6. Place a drop of water containing *Paramecia* on a clean slide and kill the animals by adding a drop or two of iodine solution. Note what happens to the cilia and trichocysts. Make a drawing of a small portion of the ectoplasm showing some of the trichocysts with the threads protruded.

7. Make a fresh preparation of the *Paramecia* and draw any animals you see which may be undergoing BINARY FISSION or CONJUGATION.

¹ B. pp. 39-47.

² It will probably be necessary to remove the cover glass and add a drop or two of quince-seed jelly to the preparation in order to quiet the animals.

VORTICELLA ¹

1. Mount a drop of water containing numerous specimens of *Vorticella*, together with a little powdered carmine, and examine with the low power. Make a drawing of a small group of the animals attached to a piece of débris.

2. Study the preparation with the high power and note that the general shape of the organism resembles a bell, projecting from which is a long contractile STALK. Note the thin, outer PELLICLE, the ECTOPLASM, and the ENDOPLASM. Determine how and where the particles of carmine are taken into the body and identify the GASTRIC VACUOLES containing the carmine particles.

3. Identify the following structures: (a) the PERISTOME, or rounded rim, at the large end of the bell; (b) the DISC, or elevated, plate-like area, included within the peristome and filling the large end of the bell; (c) the VESTIBULE, or depression, between the disc and the peristome; (d) the MOUTH, opening into (e) the GULLET which is a slender tube leading from the vestibule into the endoplasm of the body; and (f) the CONTRACTILE VACUOLE. Determine what parts of the body bear CILIA. Study the contractions of the stalk. Examine your preparation and see if you can find any stalkless, free-swimming individuals and, also, any animals undergoing division with two immature individuals attached to the same stalk.

4. Make a drawing about 3 inches long showing the general structure of the organism and as many as possible of the details mentioned above.

5. Add a little acetic carmine to your preparation, which will kill and stain the animals, and then note: (a) the long, U-shaped MACRONUCLEUS; (b) the small, round MICRONUCLEUS; (c) the STALK consisting of a SHEATH continuous with the pellicle of the bell, and surrounding the AXIAL FILAMENT composed of the individual contractile elements (MYONEMES). Add these structures to your previous drawing.

6. Mount and examine a few drops of water containing various other common species of Infusoria, such as the flattened, creeping forms (*Oxytricha*, *Stylonichia*, *Euplotes*) or the larger tubular forms (*Stentor* or *Spirostomum*). A particularly interesting type is *Didinium*, which feeds almost exclusively on *Paramecium*. Try to see them feeding if possible. Identify the various species present and compare their general structure and activities with those of *Paramecium* and *Vorticella*. (W. f. 26.)

¹ B. pp. 48-51.

GRANTIA ¹

1. Examine a good-sized specimen of *Grantia* with the naked eye and note the vase-shaped body with the central opening (OSCULUM) at one end, and the bottom, or base, where the animal was attached to some solid submerged object. Make a drawing in outline, three times normal size, to show the general structure.

2. Examine the specimen under the dissecting microscope. Note that the body wall is perforated by (a) numerous tiny openings (PORES), each of which is surrounded by (b) a cluster of calcareous SPICULES. Examine (c) the larger spicules which surround the osculum. Fill in a portion of the outline made in paragraph 1 with detail showing the nature of the external surface of the body wall.

3. With a sharp scalpel make a transverse section through the center of the body. Note the large central GASTRAL CAVITY. Next cut each piece in half in a longitudinal plane noting that the gastral cavity extends the entire length of the body and that the osculum opens directly into it.

4. Examine a portion of the internal body wall under the low power of the compound microscope with direct illumination. Note (a) that it is perforated with very fine openings (APOPYLES). Examine a cut surface of the body wall and in a favorable location note two types of parallel canals, namely, (b) the INCURRENT CANALS which open to the exterior through the pores previously noted and (c) the RADIAL CANALS which open into the gastral cavity through the apopyles but do not open to the exterior. (d) The openings (PROSOPYLES) between the incurrent and radial canals are too small to be seen. Draw to show the structure of the lining of the gastral cavity and the canals in the body wall as observed. Make a diagram of the animal which will show the course of the water currents through it.

5. Examine the isolated spicules secured by boiling a Sponge in sodium hydroxide. Note the following types: (a) long rod-like spicules which surround the osculum; (b) short rod-like spicules which surround the incurrent pores; (c) three-pronged, or triradiate, spicules from the body wall; (d) T-shaped spicules from the lining of the gastral cavity. Draw to show each type.

6. Examine a specimen of *Grantia* which shows asexual reproduction by budding. Draw to show structure as observed.

7. Examine a bath sponge. Understand that this is simply the skeleton of the animal, composed largely of fibrous SPONGIN. Note the numerous oscula and pores perforating the skeleton. Examine a small piece of a bath sponge under the low power of the microscope to get an idea of the fibrous nature of spongin.

¹ B. pp. 52-57.

HYDRA ¹

1. Examine, with the dissecting microscope, a living Hydra in a watch glass containing water. Observe the animal both when expanded and when contracted. Touch the expanded animal with a dissecting needle and observe the rapidity of contraction. Note that it is almost spherical in shape when fully contracted.

2. Examine the animal in the watch glass as before, with the low power of the compound microscope. Note: (a) the BODY, which resembles an elastic tube and is attached at one end by (b) the FOOT. (c) At the opposite end (HYPOSTOME) of the body there is (d) a central opening (MOUTH) which is surrounded by (e) a circlet of TENTACLES. Note the number of tentacles your specimen possesses and compare with others at your table.

3. Focus on the cellular body wall and note that it is composed of (a) an outer layer (ECTODERM) and (b) an inner layer (ENDODERM) which surrounds (c) a large central cavity (ENTERIC CAVITY) into which the mouth opens. Focus on one of the tentacles and note that it is also composed of ectoderm and endoderm, and that the enteric cavity continues throughout its length. Note the batteries of stinging cells (NEMATOCYSTS) embedded in the ectoderm of the tentacles.

4. Hydra commonly reproduces asexually by budding. Examine your specimen and see if any BUDS are present. At certain seasons of the year it also reproduces sexually. At such times the male gonads (TESTES), which produce the sperm, develop as swellings in the body wall just below the tentacles and the female gonads (OVARIES), which produce the eggs, develop nearer the foot.

5. Make (a) a detailed drawing of an expanded animal, showing all the parts observed above, (b) an outline drawing of a contracted animal.

6. Examine, with the low and with the high power, a prepared transverse section through the body of Hydra. Note: (a) the outer layer of ECTODERM and (b) the inner layer of ENDODERM, both of which are composed of a great number of cells, and are separated from each other by (c) a thin, noncellular layer (MESOGLOEA). These layers surround (d) the central ENTERIC CAVITY. Draw the section as observed.

¹ B. pp. 58-67.

OBELIA ¹

ASEXUAL STAGE

1. Examine, with the dissecting microscope, a specimen of *Obelia* which has been stained and mounted. Note the general form of the colony.

2. Study the preparation with the low power of the compound microscope. Note: (a) the upright stalk (HYDROCAULUS) with the side branches, each of which bears either (b) a hydra-like nutritive polyp (HYDRANTH) or (c) a club-shaped reproductive polyp (GONANGIUM). The stalk is composed of (d) an inner, deeply staining portion (COENOSARC), which is a continuation of the same material in each polyp, and (e) an outer, transparent exoskeletal sheath (PERISARC) which encloses all parts of the colony. Note that the perisarc expands into (f) a cup-shaped structure (HYDROTUECA) surrounding each hydranth and into (g) a longer, urn-shaped structure (GONOTUECA) which encloses each gonangium. Observe the constrictions in the perisarc below each polyp.

3. Study a hydranth and note: (a) the BODY WALL composed of an outer layer of ECTODERM and an inner layer of ENDODERM, both of which are continuous with the COENOSARC in the stalk; (b) the central ENTERIC CAVITY, and (c) the TENTACLES which surround (d) the MOUTH.

4. Study a gonangium and note that the club-shaped stalk (BLASTOSTYLE) which, as in a hydranth, is continuous with the coenosarc, bears numerous MEDUSA BUDS. Note the opening at the tip of the gonotheca through which the mature medusa buds escape as free-living animals.

5. Make a large drawing of an *Obelia* colony showing the structures observed.

¹ B. pp. 68-73.

GONIONEMUS ¹

1. Examine with the naked eye, in a watch glass containing water, a preserved jellyfish of the hydrozoan type, such as *Gonionemus*. Note the gelatinous consistency of the body and the umbrella, or dome, shape. The upper convex surface is called the ABORAL, or EX-UMBRELLA, and the lower concave surface is called the ORAL, or SUB-UMBRELLA.

2. Study the oral surface of the specimen with a dissecting microscope. Note: (a) the TENTACLES attached near the periphery, each with an ADHESIVE PAD near its tip; (b) the perforated, circular diaphragm (VELUM) attached below the tentacles; (c) the central structure (MANUBRIUM) suspended inside from the center of the 'umbrella' and made up of (d) the wide-lipped MOUTH, which opens into (e) the ENTERIC CAVITY.

3. Radiating from the base of the manubrium are (e) the four RADIAL CANALS bearing (f) the reproductive glands (GONADS). The radial canals lead to the periphery of the disc where they connect with (g) the CIRCULAR CANAL, which encircles the periphery near where the tentacles are attached. Note also (h) the SENSE ORGANS which are located about the margin of the body at the base of each tentacle and also between the bases of some of the tentacles.

4. Make (a) a drawing of the specimen from the oral surface and (b) a drawing from the side, to show the structures observed.

5. For comparison, examine representatives of the other classes of Coelenterates, such, for example, as the common large Jellyfish (*Aurelia*), the Sea Anemone (*Metridium*), and a calcareous Coral. (W. fs. 39-42.)

¹ B. pp. 68-73.

EXTERNAL ANATOMY OF THE STARFISH ¹

1. Examine a preserved and injected Starfish and note (a) the star-shaped, radially symmetrical body consisting of (b) a CENTRAL DISC from which (c) five, pointed ARMS radiate. Note that (d) the convex upper, or ABORAL, surface is markedly different from the flat under, or ORAL, surface. Draw the specimen from the aboral surface, in outline, natural size.

2. Note the circular MADREPORITE embedded in the body wall of the central disc between two of the arms. These two arms constitute the BIVIUM and the remaining three arms the TRIVIUM. A plane of symmetry which will divide the animal in right and left halves passes through the madreporite, central disc, and the median longitudinal plane of the middle arm of the trivium.

3. Examine the aboral surface of your specimen under the dissecting microscope and note that the external surface of the body wall is thickly studded with blunt calcareous SPINES, around the bases of which, as well as in the areas between, pincer-like PEDICELLARIAE will be found in great numbers. Also numerous soft tubular BRANCHIAE, which function in respiration, will be seen projecting through the body wall. These are particularly well seen in an injected specimen. Add the details observed in paragraphs 2 and 3 to your outline drawing.

4. Examine the oral surface of your specimen, noting (a) the five AMBULACRAL GROOVES radiating from the central disc to the tip of each arm and filled with (b) numerous projecting TUBE FEET, each of which ends in (c) a SUCTION DISC. Note further (d) the MOUTH in the center of the disc protected by (e) a series of large SPINES developed at the base of each ambulacral groove. Draw the oral surface of your specimen in outline and fill in the detail in one arm as observed.

5. Examine the oral surface of a dried specimen and note (a) the arrangement of the spines along the edges of the ambulacral grooves and (b) the arrangement of the AMBULACRAL OSSICLES forming the roof of the grooves, through which the tube feet project. Draw a portion of one arm to show the structure as observed.

6. For comparison, examine a number of other common species of Echinoderms, such, for example, as the Brittle Star (*Ophiura*), Sea Urchin (*Arbacia*), Sand Dollar (*Echinarachnius*), and Sea Cucumber (*Cucumaria*). (W. f. 47.)

¹ B. pp. 74-76.

INTERNAL ANATOMY OF THE STARFISH¹

1. Place a preserved, injected Starfish, in its natural position, aboral surface up, in a wax-bottomed dissecting pan and cover with water. Turn the pan so that the two arms of the bivism are pointing away from you, and fasten the animal in place by inserting a pin through the tip of each arm.

2. A portion of the body wall covering each arm of the trivium may now be carefully removed as follows: (*a*) Snip off the extreme tip of an arm with the scissors; (*b*) insert point of scissors in the end of the arm and carefully cut through the aboral wall about $\frac{1}{4}$ inch to the right of the median line; (*c*) extend the cut to the central disc, aiming the scissors throughout at the madreporite; (*d*) make the same cut to the left of the median line; (*e*) beginning at the tip of the arm carefully raise the severed portion of the body wall, detaching it from the underlying tissues and leaving them carefully in place; (*f*) make a transverse cut through the body wall at the edge of central disc and discard the detached portion of body wall; (*g*) separate the cut edges of the arm and hold apart with pins.

3. Carry out the procedure given in paragraph 2 for each of the two remaining arms of the trivium and then dissect off and discard the body wall of the central disc, excepting the area immediately surrounding the madreporite, thus exposing the underlying STOMACH. Note the connections of the stomach with (*a*) the large paired PYLORIC CAECA which extend into each arm. Remove the caeca from one arm and find (*b*) a pair of small feathery GONADS extending into the arm from the central disc. Identify (*c*) the RETRACTOR MUSCLES extending from the wall of the stomach to their attachment to the ambulacral ossicles in the arm. Examine (*d*) the AMPULLAE of the tube feet which lie on either side of the ridge of ossicles in the median line of the arm.

4. Draw the dissected animal in outline and fill in the detail in the central disc and in two of the arms to show the structures as observed.

5. Carefully dissect out the stomach after clipping the retractor muscles, taking particular care not to injure the madreporite. Find the STONE CANAL running orally from the madreporite to the mouth region. Try to trace it to the RING CANAL encircling the mouth. Make a diagram to show the arrangement of these parts.

¹ B. pp. 76-80.

EXTERNAL ANATOMY OF THE EARTHWORM¹

1. Examine an Earthworm and note the long, tubular body which is composed of a large number of SEGMENTS. Identify the anterior, posterior, dorsal, and ventral regions of the body. Count the segments of your specimen and compare the number with others at your table. Note: (a) the MOUTH, which is situated at the anterior end of the body below the projecting lobe (PROSTOMIUM); (b) the ANUS situated at the posterior end of the body, where it can be seen as a vertical slit in the last segment, and (c) the swollen region (CLITELLUM) lying in the region between segments 32 and 37 in *Lumbricus terrestris*, a common species.

2. With one hand take hold of the anterior end of the Earthworm and draw the body through the fingers of your other hand. The rough feeling is due to the presence of bristles (SETAE) which project through the body wall. Ascertain the arrangement of the setae and the number present on each segment.

3. Examine your specimen with the dissecting microscope and find the following openings: (a) openings of the SPERM DUCTS in the swellings on the ventral surface of segment 15; (b) openings of the OVIDUCTS just lateral to the inner double row of setae in segment 14; (c) openings of the SEMINAL RECEPTACLES in the grooves between segments 9 and 10, and 10 and 11, on a line with the outermost row of setae; (d) openings of the NEPHRIDIA just lateral and anterior to the setae of the inner row on either side of each segment; (e) openings of the DORSAL PORES on the anterior end of each segment in the median dorsal line.

4. Make (a) a drawing, twice natural size, of the anterior forty segments of the body from the ventral surface, and (b) a drawing, at the same magnification, of the posterior ten segments of the body from the dorsal surface to show the structure as observed.

5. For comparison, examine a number of other species of Annelida, such, for example, as a free-swimming type, *Nereis* (p. 83), or *Autolytus* which reproduces by budding; a tube-dwelling type (*Amphitrite*, *Arenicola*, or *Chaetopterus*); and the medicinal Leech (*Hirudo*). (W. f. 45.)

¹ B. pp. 81-84.

INTERNAL ANATOMY OF THE EARTHWORM¹ (1)

1. Place a preserved Earthworm, dorsal surface up, in a dissecting pan and fasten it with one pin through the prostomium at the anterior end of the body, and another through the posterior end of the body. With fine scissors cut very carefully through the body wall in the median dorsal line, beginning just posterior to the clitellum. Extend the cut to the anterior end of the animal, being careful to cut only through the body wall so as not to injure the intestine just below. Beginning at the posterior end of the cut, spread the cut edges by carefully cutting away the segmental partitions (SEPTA) which attach the body wall to the alimentary canal. Pin the cut edges of the body wall to the wax in the pan. Slant the pins away from the specimen so as not to interfere with your study.

2. Examine the specimen and note: (a) the rather thick BODY WALL consisting for the most part of muscular tissue; (b) the body cavity (COELOM) which is divided into a linear series of chambers by the septa; (c) the ALIMENTARY CANAL running the length of the body through the coelom as a straight tube, and (d) the DORSAL BLOOD VESSEL, generally full of coagulated blood, which runs along the top of the alimentary canal. It receives (i) small segmental branches coming from the body wall and alimentary canal, and (ii) connects, in segments 8 to 12, with five pairs of contractile, thick-walled vessels (AORTIC LOOPS). The latter pass around the digestive tract and unite below with the VENTRAL BLOOD VESSEL.

3. Examine the alimentary canal and note that it consists of the following parts: (a) the MOUTH which opens just below the overhanging prostomium; (b) the thick, muscular PHARYNX extending back to segment 6 and attached to the body wall by many fine muscles; (c) the thin-walled ESOPHAGUS, largely obscured by (d) the overlying REPRODUCTIVE ORGANS, extending between segments 7 and 14; (e) the CROP at about segment 14; (f) the thick-walled, muscular GIZZARD at about segment 18; (g) the INTESTINE extending from segment 20 to (h) the ANUS at the extreme posterior end of the body.

4. Make a drawing, twice natural size, to show these structures as observed, being careful that each organ is drawn correctly with reference to the segments.

¹ B. pp. 84-95.

INTERNAL ANATOMY OF THE EARTHWORM¹ (2)

1. Fasten the specimen, which you worked on the last time, in a dissecting pan as before. Make a transverse cut through the alimentary canal, a few segments posterior to the gizzard. Gently move the cut ends slightly to one side and find the whitish **VENTRAL NERVE CORD** lying directly below in the median line. Carefully remove the portion of the alimentary canal lying anterior to the cut just made, as far as the pharynx, but in so doing be sure first to cut all the septa which hold it, so as not to disturb the underlying nerve cord.

2. Trace the nerve cord to the anterior end of the pharynx, where it divides to form a nerve collar (**CIRCUMPHARYNGEAL CONNECTIVES**) which encircles the anterior end of the pharynx. Examine the dorsal surface of the nerve collar under the dissecting microscope and note the bilobed swelling (**CEREBRAL GANGLION**) which constitutes the **BRAIN** of the animal. If the dissection has been carefully made, nerves can be seen extending from the cerebral ganglion to the extreme anterior end of the body.

3. Examine the exposed portion of the nerve cord with the dissecting microscope and note that, in each segment, it expands to form a slight enlargement (**GANGLION**) from which two pairs of **LATERAL NERVES** arise. Anterior to the ganglion in each segment, find another smaller pair of nerves. All these nerves can be traced into the near-by muscles of the body wall.

4. Continue your examination with the dissecting microscope and note, in each segment, lying close to the body wall on either side of the nerve cord a tiny, greatly coiled, tubular structure (**NEPHRIDIUM**) which is an important excretory organ. Note also the glistening, white longitudinal muscle tissue of the body wall. Remove one or more of the nephridia with a pair of fine forceps. Place on a slide or in a watch glass with water. Study under the microscope and see if you can determine the main structural features.

5. Make an enlarged drawing of the anterior end of the Earthworm to show the structures as observed.

¹ B. pp. 95-98.



BODY PLAN OF THE EARTHWORM¹

1. Examine, with the low and high power, a prepared transverse section through the body of a small Earthworm. Draw the section in outline, about four inches in diameter, and then fill in a quadrant to show the general structure as follows:

(a) BODY WALL, which consists of: (i) a very thin, transparent outer membrane (CUTICLE); (ii) a layer of elongated, epidermal cells (EPIDERMIS); (iii) a layer of CIRCULAR MUSCLES and (iv) a thicker layer of LONGITUDINAL MUSCLES, which together comprise most of the body wall; and (v) a thin layer of PERITONEAL EPITHELIUM lining the coelom. Note (vi) the bristle-like SETAE, with attached muscle fibers, projecting through the body wall. Determine their number and arrangement and compare with paragraph 2, page 279.

(b) ALIMENTARY CANAL, which appears in a transverse section as a ring of tissue with a dorsal infolding which forms the TYPHLOSOLE. The wall of the canal consists of (i) an outer layer of cylindrical cells (CHLORAGOGEN LAYER) which also fill the cavity of the typhlosole; (ii) a muscular layer with both circular and longitudinal fibers; (iii) a vascular layer with many tiny blood vessels; and, finally, (iv) a layer of elongated cells (LINING EPITHELIUM) which form the inner lining of the tract and are the essential agents in the digestion and absorption of food. A section through the dorsal and through the ventral blood vessels can be noted, lying above and below the digestive tract respectively.

(c) NERVE CORD, which consists of two distinct structures, the outer envelope, or SHEATH, and the inner NERVOUS PORTION. The sheath consists of a thin, outer epithelial layer which encloses a thicker supporting layer. Embedded in the supporting layer, dorsally, are the three GIANT FIBERS which run the length of the cord and, ventrally, the SUBNEURAL blood vessel. The nervous portion of the cord within the sheath is bilobed and contains nerve cells and fibers. If the section happens to be through the region of a ganglion a pair of the lateral nerves may be seen.

¹ B. pp. 84-86.

EXTERNAL ANATOMY OF THE CRAYFISH¹ (1)

1. Examine a preserved Crayfish and note that the body, which is entirely covered with a chitinous EXOSKELETON, consists of a rigid anterior portion (CEPHALOTHORAX) and a jointed, flexible, posterior portion (ABDOMEN).

2. The portion of the exoskeleton covering the cephalothorax is known as the CARAPACE. The latter ends anteriorly in a dorsal projection (ROSTRUM). Examine the carapace and note the indentation (CERVICAL GROOVE) in the exoskeleton which marks the division between the HEAD and THORAX. Note: (a) the short ANTENNULES; (b) the long ANTENNAE with the opening of (c) a GREEN GLAND, or kidney, on the basal joint of each; (d) the compound EYES; and (e) the ventral MOUTH concealed by appendages.

3. The abdomen consists of six similar segments and, at the posterior end, a median structure (TELSON) which is generally regarded as a seventh abdominal segment. Note the ANAL OPENING on the ventral surface of the telson. Examine the ABDOMINAL SEGMENTS and note how they are joined together so as to permit movement. A pair of BIRAMOUS APPENDAGES is attached to each abdominal segment except the telson. In the male, the first two pairs of abdominal appendages are modified and enlarged for the transfer of sperm, while in the female the first pair is greatly reduced. In the female, there is also a cavity (SEMINAL RECEPTACLE) in the mid-ventral line between the fourth and fifth pairs of walking legs. Determine the sex of your specimen.

4. Examine the exoskeleton of a detached abdominal segment and note: (a) the dorsal, arched portion (TERGUM); (b) the ventral, calcified bar (STERNUM); and (c) the projecting, lateral portions (PLEURA). Examine the attached biramous appendages and note: (d) the basal portion (PROTOPODITE) which is attached to the body and bears (e) two jointed branches (EXOPODITE and ENDOPODITE).

5. Make (a) a drawing of the entire animal from the left side and (b) a drawing of a detached abdominal segment from one end.

6. For comparison, examine a number of other common species of Crustacea, such, for example, as the tiny Water-flea (*Daphnia*) or the one-eyed *Cyclops*, the sessile Barnacle (*Balanus*), the Crab (*Callinectes* or *Gelasimus*), the Spider Crab (*Libinia*), and the terrestrial Pill-bug (*Oniscus*). (W. f. 51.)

¹ B. pp. 99-100.

EXTERNAL ANATOMY OF THE CRAYFISH¹ (2)

1. Carefully cut off a portion of the carapace from the left side of your specimen, thus exposing the left GILL CHAMBER containing the GILLS. Then lay the animal on its right side under water. Note the feathery character of the gills and their attachment either to the appendages or to membranes present at the base of the appendages. Find the modified, paddle-shaped portion (SCAPHOGNATHITE) of the second maxilla, which lies in the anterior end of the gill chamber and by its movements keeps a current of water bathing the gills.

2. Examine and identify the 19 pairs of appendages present on the Crayfish, using the figures and description in your textbooks. In doing this it will be well to begin at the posterior end of the animal and work forward. The appendages may be summarized as follows:

(a) ABDOMINAL APPENDAGES, six pairs, namely, the UROPOD and five pairs of SWIMMERETS. The first two pairs of swimmerets are not typical and are different in the two sexes.

(b) THORACIC APPENDAGES, eight pairs, namely, five pairs of WALKING LEGS and three pairs of MAXILLIPEDS.

(c) HEAD APPENDAGES, five pairs, namely, two pairs of MAXILLAE, one pair of MANDIBLES, one pair of ANTENNAE, and one pair of ANTENNULES. (W. fs. 64, 65.)

3. Beginning again at the posterior end of the abdomen, carefully remove all the appendages one by one from the left side of the animal and pin each one in a dissecting pan in its proper order and position. In removing them, be sure to get the whole of each appendage, including the gills when present. The small appendages around the mouth must be handled very carefully with fine forceps.

4. Study and make a drawing of the following appendages: (a) ANTENNA; (b) SECOND MAXILLA; (c) THIRD MAXILLIPED; (d) FIRST and SECOND WALKING LEGS, and (e) THIRD and SIXTH ABDOMINAL APPENDAGES. Identify and label the homologous parts in each.

¹ B. pp. 100-104.

INTERNAL ANATOMY OF THE CRAYFISH¹

1. Secure a good-sized preserved Crayfish and place in dissecting pan. Hold the animal firmly with one hand, dorsal surface up, and insert the points of the scissors under the center of the posterior margin of carapace. Beginning at this point, cut through the carapace in the mid-dorsal line and continue the cut to the base of the rostrum, stopping just back of the eyes. From this point make transverse cuts through the carapace to the right and to the left. Each cut should extend ventrally from the mid-dorsal line to the ventral edge of the carapace, just posterior to the eyes and at the base of the antenna. The right and left halves of the carapace, which have now been completely severed, may be carefully detached from the underlying tissues and discarded, thus exposing the internal organs of the thorax and head regions, including the lateral gill chambers.

2. Note the delicate pigmented membrane which, if unbroken, covers the internal organs. Remove the membrane and note: (*a*) the thin-walled STOMACH in the midline near the anterior end of the body; (*b*) the muscular HEART lying in the PERICARDIAL CAVITY, the walls of which consist of (*c*) a delicate PERICARDIUM. Find: (*d*) the large ANTERIOR MEDIAN ARTERY which extends forward from the anterior margin of the heart; and (*e*) the DORSAL ABDOMINAL ARTERY which extends posteriorly through the abdomen. On either side and below the heart note: (*f*) a DIGESTIVE GLAND; and (*g*) a GONAD just anterior. Carefully remove the heart, taking care not to disturb the other organs. Examine it under water and find (*h*) three pairs of openings (OSTIA) through which the blood enters the heart from the surrounding pericardial cavity.

3. Examine the stomach and locate: (*a*) the short ESOPHAGUS, running dorsally from the mouth and opening into the ventral surface of the stomach at the anterior, or CARDIAC PORTION. The digestive glands open into the posterior, or PYLORIC PORTION of the stomach. Trace (*b*) the intestine posteriorly from the stomach to the abdomen. With the scissors cut through the entire length of the abdominal wall in a mid-dorsal line. Separate the cut edges and find (*c*) the intestine lying between the abdominal muscles: trace it to the external opening on the ventral surface of the telson. Make a drawing of the alimentary canal to show

¹ B. pp. 104-112.

the structure as observed. Remove the stomach, open and note (*d*) the large anterior CARDIAC PORTION which receives food from the esophagus and which contains (*e*) the GASTRIC MILL with (*f*) chitinous DENTICLES for grinding. Note (*g*) the STRAINER between the cardiac and pyloric portions.

4. Examine the large segmentally arranged EXTENSOR MUSCLES in the abdomen and also the FLEXOR MUSCLES which run from the abdomen to their anterior attachment on the right and left sides of the ventral wall of the thorax. Understand the actions of these two sets of muscles.

5. Separate the extensor muscles in the median line and locate the underlying ventral NERVE CORD. Trace the latter throughout the length of the abdomen noting the GANGLIA and the BRANCHES given off to the adjacent muscles. Next trace the nerve cord anteriorly through the thorax and to the anterior end of the body. In the thorax the cord lies concealed under the muscle tissue and a series of chitinous plates. Carefully dissect and expose the nerve cord throughout the entire length of the body. Note the double character of the cord. This is well-shown in the posterior part of the thorax, where it is pierced by the sternal artery, and also in the head, where the nerve cord passes around either side of the esophagus and then unites again to form the important CEREBRAL GANGLION, from which nerves are given off to the eyes, antennules, and antennae. Find the sac-like GREEN GLANDS, which function in excretion, lying near each eye at the base of the antenna, through which they open.

EXTERNAL ANATOMY OF THE GRASSHOPPER¹

1. Examine a large Grasshopper and note that the body, as previously seen in the Crayfish, is completely enclosed in the chitinous exoskeleton. Note further that the body is definitely divided into the HEAD, the THORAX, to which the legs and wings are attached, and the ABDOMEN with distinct segmentation. Make an outline drawing from the left side to show the general body plan.

2. Examine the head and note the following structures: (a) the very flexible, jointed ANTENNAE; (b) the two large COMPOUND EYES; (c) three SIMPLE EYES (OCELLI) on the front of the head in the region of the 'fore-head'; (d) the CLYPEUS forming a median portion of the exoskeleton in the front of the head with (e) the upper lip (LABRUM) lying just ventral.

3. Carefully remove the labrum and find, underneath, the chewing (MANDIBULATE) mouthparts as follows: (a) a pair of toothed MANDIBLES; (b) a pair of MAXILLAE to each of which (c) a MAXILLARY PALP is attached, and finally (d) the lower lip (LABIUM) divided in the midline and bearing a LABIAL PALP on each side. Draw the head from the front, showing the structures as observed under paragraphs 2 and 3.

4. Examine the thorax and note the heavy exoskeleton, particularly on the ventral surface. There are three thoracic segments designated as the PROTHORAX, MESOTHORAX, and METATHORAX, each of which bears a pair of LEGS and the last two, in addition, a pair of WINGS each. Note that the articulation between the prothoracic and mesothoracic segments permits movement, but that the mesothoracic and metathoracic segments are rigidly joined.

5. Examine the wings and note the difference in the character of the two pairs. Remove one of the large metathoracic legs. Note the following segments: (a) the COXA, attached to the body; (b) the small TROCHANTER, attached to the distal end of the coxa; (c) the large tapering FEMUR; (d) the straight, rod-like TIBIA with two rows of spines towards the distal end; (e) the five-jointed TARSUS with a pair of very sharp CLAWS on the last segment between which is a fleshy pad (PULVILLUS). Make outline drawings of the two wings and a metathoracic leg.

6. Examine the abdomen. Identify the eleven segments of which it is composed and note that most of them are so attached as to permit a considerable freedom of movement. Note further that the exoskeleton of the abdomen, as in the Crayfish, is typically divided into a dorsal portion (TERGUM) and a ventral portion (STERNUM), except in the first and the last abdominal segments, in which the sterna are lacking. Note the fusion of the sterna in abdominal segments 9 and 10. Find a pair of breathing pores (SPIRACLES) on the mesothoracic and metathoracic segments and on the first eight abdominal segments. Note the TYMPANUM on each side of the first abdominal segment.

¹ B. pp. 113-117.

INTERNAL ANATOMY OF THE GRASSHOPPER¹

1. Secure a large preserved Grasshopper and with scissors cut off the wings and the legs, close to the body. Pin the specimen, dorsal surface up, in a wax-bottomed pan, and cover with water. Carefully insert the tips of sharp-pointed scissors through the dorsal body wall, in the midline, at the extreme posterior end of the abdomen. Make a median longitudinal incision extending from the point of insertion throughout the length of the abdomen and the thorax. Be careful to cut just through the body wall so as not to injure the underlying tissues. Carefully separate the cut edges and then pin in such a way as to hold them apart.

2. Examine the internal organs and note the large ALIMENTARY TRACT running throughout the length of the body. The following parts may be noted: (a) the tubular ESOPHAGUS extending from the mouth into the thorax, where it gradually enlarges to form (b) the CROP. Note (c) the SALIVARY GLANDS extending along the wall of the crop anteriorly to the mouth cavity into which they open. Posteriorly the crop narrows to form (d) the muscular GIZZARD (PROVENTRICULUS) which leads in turn to (e) the rather small STOMACH (VENTRICULUS). Opening into the anterior end of the stomach are (f) the GASTRIC CAECA.

3. Posterior to the stomach a mass of fine, coiled MALPIGHIAN TUBULES, which are excretory in function, obscure the underlying INTESTINE, into the anterior end of which they open. In the posterior part of the abdomen, the enlarged portion of the intestine (RECTUM) continuing to the exterior is covered by a pair of GONADS which lie close to the dorsal body wall. Trace the intestine to the anal opening.

4. Make a drawing of the internal anatomy which will show the structures observed in the preceding paragraphs.

5. After carefully cutting anteriorly and posteriorly, remove the entire alimentary canal and attached structures from the body, but leave the gonads in place. Find the duct leading from one of the gonads and trace it ventrally to the point where it unites with the duct from the other gonad and forms a common duct to the exterior.

6. Note the large leg and wing MUSCLES in the thorax. With the forceps remove a small piece of muscular tissue, mount and examine microscopically in order to find some of the widely distributed air tubes (TRACHEAE) which are abundant in the muscle tissue. Note the relation existing between spiracles and tracheae along the abdominal wall.

7. Examine the ventral body wall and find the median NERVE CORD extending the length of the body in the mid-ventral line. Note its general nature and also the enlarged nerve centers (GANGLIA) distributed along it; two of which are in the head, three in the thorax, and five in the abdomen. Make a drawing to show the structure of the nervous system.

¹ B. pp. 117-123.

EXTERNAL ANATOMY OF THE HONEY BEE¹ (1)

1. Examine a freshly killed or preserved Honey Bee of the worker type and note that the body is divided into HEAD, THORAX, and ABDOMEN. Study the specimen with the dissecting microscope. Observe that the thorax is composed of three segments, each of which bears a pair of jointed legs. The second and third thoracic segments also bear a pair of wings. Observe that the abdomen is composed of six visible segments. The exoskeleton of each of these segments is made up of the dorsal TERGUM and the ventral STERNUM. At the posterior end of the abdomen is the ANUS and the opening for the STING APPARATUS. Make an enlarged drawing of the animal from the left side to show the structures observed.

2. Remove the head, place it on a slide, and study the anterior surface under the dissecting microscope. Note: (a) the large compound eyes, which project from either side of the head; (b) the small simple eyes (OCELLI) in the center and almost on top of the head; (c) the pair of jointed ANTENNAE and just below them on the anterior surface; (d) a median, dome-shaped structure (CLYPEUS) to which is attached (e) the upper lip (LABRUM). As seen from the anterior surface the chief mouth parts consist of (f) a long, median tongue (GLOSSA) with (g) a spoon-like tip (LABELLUM); (h) a pair of LABIAL PALPS, one on each side of the tongue; (i) a pair of wider, projecting MAXILLAE, lateral to the palps; and (j) a pair of MANDIBLES, attached near the labrum. The mandibles are generally closed, in which position they obscure the underlying labrum and (k) EPIPHARYNX. Make an enlarged drawing of the head from the anterior surface to show the structures observed.

3. With fine forceps remove the posterior portion of the abdomen. Place it on a slide under the dissecting microscope, and with a pair of needles dissect out the STING APPARATUS. Note the following parts: (a) a pair of BARBED DARTS, which with the sheath form a long, rigid, median structure; (b) a pair of fleshy STING FEELERS, one on either side of the darts; and (c) the POISON SAC with attached POISON GLANDS. Draw to show the structures observed.

¹ B. pp. 123-128.

EXTERNAL ANATOMY OF THE HONEY BEE¹ (2)

1. With fine forceps, carefully remove the left PROTHORACIC LEG, being sure that you secure all the joints. Mount and examine it with the dissecting microscope and also with the low power of the compound microscope. Note that it is composed of five joints which, beginning with the one attached to the body, are designated as follows: (a) COXA; (b) TROCHANTER; (c) FEMUR; (d) TIBIA, and (e) the five-jointed TARSUS. Note: (f) the feathery BRANCHED HAIRS, for gathering pollen, which are present on all the joints except the tarsus; (g) the POLLEN BRUSH and (h) the flattened spine (VELUM) on the tibia; (i) the circular ANTENNA COMB on the first joint (BASITARSUS) of the tarsus, which works with the velum on the tibia to form an ANTENNA CLEANER; (j) the EYE BRUSH, also on the first joint of the tarsus, and (k) the FOOT, or terminal portion of the tarsus, which consists of a fleshy adhesive pad (PULVILLUS) and a pair of notched CLAWS. Draw to show the structures observed.

2. Remove, mount, and study as before, the left MESOTHORACIC LEG. Observe the POLLEN SPUR on the tibia, which is used to dislodge the pollen pellets from the pollen basket on the tibia of the metathoracic leg. Draw a portion of the leg to show this structure.

3. Remove, mount, and study as before the left METATHORACIC LEG. Note: (a) the concavity (POLLEN BASKET) on the outer surface of the tibia; (b) the row of short, stiff spines (PECTEN) present on the distal end of the tibia; (c) a concave plate (AURICLE) on the inner surface of the first joint of the tarsus; and (d) the POLLEN COMBS, on the first joint of the tarsus. Draw a portion of the leg to show these structures.

4. For comparison, examine a number of other common species of Insects, such, for example, as the primitive Silver-fish (*Lepisma*), Dragon-fly (*Libellula*), Giant Water-bug (*Benacus*), House-fly (*Musca*), Mosquito (*Culex*), Flea (*Pulex*), Stag Beetle (*Passalus*), and the large Black Ant (*Camponotus*).

¹ B. pp. 123-128.

LIFE HISTORY OF THE MOTH¹

1. The life history of the Moths and of other Insects with complete metamorphosis consists of four stages, namely, EGG, LARVA, PUPA, and ADULT.

(a) EGG. The eggs of a Moth are generally laid on, and attached to, leaves which later serve as food for the larvae. Examine, with the dissecting microscope, a preparation of a leaf with the attached eggs and make a drawing.

(b) LARVA. Examine the segmented, worm-like, larval stage of the moth (CATERPILLAR) and make a drawing to show the following structures: (i) the head, which appears as one segment and bears on its anterior surface tiny, simple eyes (OCELLI) and, laterally on each side of the mouth, a pair of jaws (MANDIBLES); (ii) the THORAX, consisting of three segments, each of which bears a pair of small jointed appendages with sharp hooks, and (iii) the ABDOMEN, consisting of the posterior nine segments, of which five bear unjointed appendages, known as PROLEGS. Note the openings (SPIRACLES) of the tracheal tubes on each side of certain segments. Draw the animal from the left side to show the structures observed.

(c) PUPA. Examine the silky COCOON which the animal spins and in which it encloses itself at the end of the larval period. Carefully open the cocoon by making a longitudinal cut through the wall with the tips of the scissors. Remove the living pupa and examine under the dissecting microscope. Identify the HEAD, THORAX, ABDOMEN, ANTENNA CASES, WING CASES, and LEG CASES. Make drawings of (i) the cocoon, and (ii) the pupa from the ventral surface.

(d) ADULT. Examine an adult Moth. Identify (i) the HEAD, with EYES and ANTENNAE; (ii) the THORAX, with FORE and HIND WINGS, and three pairs of LEGS; and (iii) the segmented ABDOMEN. Compare the various structures with those seen in the Bee. Make a drawing of the dorsal surface, showing all structures possible.

¹ B. pp. 130-133.

CLAM¹

1. The shell of a Clam consists of right and left halves (VALVES) which are hinged together along the dorsal surface. Concentric lines of growth are visible on the shell, which radiate from a dorsal portion, or UMBO, where growth of the shell started. Draw the external surface of the left valve.

2. Carefully remove the left valve from your specimen, noting the structure of the HINGE and the attachments of the ANTERIOR and the POSTERIOR ADDUCTOR MUSCLES to the interior of the shell. It is necessary to cut both of these muscles before removing the valve. Note that the internal organs are enclosed by a membranous MANTLE which lines both valves of the shell. The space between the two halves of the mantle, in which the organs lie, is known as the MANTLE CAVITY. Turn back the left half of the mantle, cutting a little at each end, and thus expose the structures in the mantle cavity as follows: (a) the large dorsal VISCERAL MASS, from which (b) the ventral muscular FOOT extends; (c) the delicate, striated GILLS; and (d), at the posterior end of the mantle, the dorsal (EXHALENT) and the ventral (INHALENT) SIPHONS.

3. Below the anterior adductor muscle, note the two pairs of PALPS, between which the MOUTH is situated. At the posterior end of the body find the ANUS, which opens into the EXHALENT SIPHON, dorsal and slightly posterior to the posterior adductor muscle. Trace the INTESTINE anteriorly from the anus to the HEART. The latter lies in a median dorsal position enclosed in the thin, delicate PERICARDIUM. The heart consists of a single VENTRICLE through which the intestine passes, and two small, thin-walled AURICLES lying laterally and below and attached to the pericardium. The auricles are easily destroyed in the dissection. Locate the anterior aorta continuing anteriorly from the heart and the posterior aorta continuing posteriorly along the intestine. On the latter note, in some species, the BULBUS ARTERIOSUS a short distance back of the heart.

4. Make an enlarged drawing showing the internal structure of the Clam as observed.

5. Examine the external structure of various other types of Molluscs, such as (a) the common garden Slug which lacks an external shell, (b) a Snail with a spirally-coiled shell, and (c) a free swimming Squid with prominent head region.

¹ B. pp. 139-148.

EXTERNAL ANATOMY OF THE CHORDATES¹

1. Examine the worm-like Chordate, *Dolichoglossus*, and note the following structural features: (a) the blunt hollow PROBOSCIS at the anterior end, just back of which is (b) the COLLAR encircling the anterior end of the body. Posterior to the collar on the dorsal side of the body is (c) a double row of small openings, the GILL SLITS, which are believed to indicate chordate relationship. Internally *Dolichoglossus* possesses a notochord-like structure and a dorsal nervous system, both of which are also generally regarded as additional evidence of Chordate relationship. On the whole it must be emphasized that the taxonomic position of this species is open to considerable question. Draw to show the external structures.

2. Examine one of the so-called Sea-squirts, such as *Molgula*. In the adult condition these animals are attached to some solid object and show no external characters which would link them with the typical Chordate. The rather cylindrical body is completely enclosed in (a) a TUNIC largely composed of cellulose. Note (b) the ORAL APERTURE and (c) the ATRIAL APERTURE. During life a current of water is continually drawn into the oral aperture, then passes through (d) the inner BRANCHIAL CHAMBER, the walls of which contain numerous ciliated GILL SLITS. Next the water passes into the surrounding ATRIAL CAVITY and then out of the body through the atrial aperture. The tiny, microscopic larval stage of this group is a free-swimming tadpole-like organism which unquestionably possesses the three basic chordate features. Examine a preparation of the larval stage if available and note the general structural arrangements. Draw both stages in outline to show structures observed.

3. Examine the small free-swimming Chordate, *Branchiostoma*, more commonly known as *Amphioxus*. Note that the elongated body is definitely fish-like in its general shape. Identify the anterior, posterior, dorsal, and ventral surfaces. Note: (a) the opening (ORAL HOOD) at the extreme anterior end of the body surrounded by (b) a fringe of CIRRI and opening into (c) a cavity (VESTIBULE) at the base of which is (d) the jawless MOUTH. (e) The DORSAL FIN will be found extending practically the length of the body on the dorsal side and joining posteriorly with (f) the TAIL (CAUDAL) FIN. The latter is continuous with (g) the VENTRAL FIN, which extends anteriorly about one-third the length of the body. Note further (h) a marked segmentation (METAMERISM) of the muscle tissue in the body wall. On the ventral surface locate (i) the ANAL OPENING near the anterior end of the caudal fin and also (j) the opening (ATRIOPORE) at the posterior end of the ventral (k) METAPLEURAL FOLD which encloses the ATRIAL CAVITY. Draw in outline to show the structure as observed.

¹ B. pp. 149-152.

EXTERNAL ANATOMY OF THE VERTEBRATES ¹(1)

A. CYCLOSTOMATA

1. Examine a Lamprey (*Petromyzon marinus*) and note the long cylindrical eel-shaped body covered with a soft slimy skin which entirely lacks rigid exoskeletal structures. Identify the anterior, posterior, dorsal, and ventral surfaces. Note: (a) the jawless MOUTH which lies at the bottom of (b) the suctorial BUCCAL FUNNEL with (c) a number of horny TEETH on each side. Note further (d) a pair of large EYES, and between them on the dorsal surface of the head (e) a single olfactory opening (NASAL APERTURE). Laterally and posteriorly to the eyes, on each side of the body, are (f) seven GILL SLITS opening through the body wall. Locate (g) the UROGENITAL APERTURE near the posterior end of the body. Examine the unpaired fins on the dorsal and ventral surfaces and around the tail region. Draw in outline to show general structure.

B. PISCES, OR BONY FISHES

2. Examine a small specimen of some common Bony Fish and note the pointed, laterally compressed body adapted for rapid swimming, with a well-developed HEAD, TRUNK, and TAIL. Identify the anterior, posterior, dorsal, and ventral surfaces. Examine (a) the overlapping SCALES which almost completely cover the body. Note: (b) the large MOUTH with (c) upper and lower JAWS and (d) numerous TEETH. Note further (e) the EYES; (f) the paired dorsal OLFACTORY OPENINGS; and (g) the OPERCULUM covering the GILLS on each side of the body. Examine: (h) the FINS and identify the two unpaired DORSAL FINS; the CAUDAL FIN with dorsal and ventral lobes (HOMOCERCAL); the single ventral fin; and, finally, the two pairs of PAIRED FINS, namely the PECTORAL FINS, one on each side of the body just back of the operculum, and the PELVIC FINS, attached to the ventral surface. Draw in outline to show general structure.

C. AMPHIBIA

1. Examine a Frog and note: (a) the GENERAL FORM of the animal; (b) the division into HEAD and TRUNK; (c) the FORE and HIND LIMBS;

¹ B. pp. 152-157; 164-167.

(*d*) the OPENING of the CLOACA; (*e*) the character of the SKIN (the microscopic structure of the skin is studied in a later exercise on page 319); and (*f*) the difference in COLOR between the dorsal and ventral surfaces.

2. Examine the head and note the following structures: (*a*) the large MOUTH; (*b*) the pair of small, anterior openings, or NOSTRILS (EXTERNAL NARES); (*c*) the pair of circular EAR DRUMS (TYMPANIC MEMBRANES); (*d*) the protruding EYES; and (*e*) the tiny nodule (BROW SPOT) in the skin between the eyes. Note how the lower EYELIDS cover the eyes and how each eye may be drawn into a cavity (ORBIT) in the skull and thus protected from injury.

3. Examine the fore limb and identify the UPPER ARM, FOREARM, and HAND; the latter with WRIST and DIGITS. Examine the HIND LIMB and identify the THIGH, SHANK, and FOOT; the latter with ANKLE, DIGITS, and INTERDIGITAL WEB. Note the difference in length between the two pairs of limbs.

4. Make a drawing of the Frog, showing as many of the above characters as possible.

EXTERNAL ANATOMY OF THE VERTEBRATES ¹ (2)

A. REPTILIA

1. Examine a small Turtle and note: (a) the general form of this animal encased in (b) the heavy box-like SHELL composed of (c) a dorsal portion (CARAPACE) and (d) a ventral portion (PLASTRON); (e) the highly developed HEAD with (f) a long flexible NECK; (g) the clawed PENTADACTYL LIMBS; and (h) the short TAIL. Note (i) the scaly character of the skin on the uncovered parts of the body.

2. Examine the flattened, triangular-shaped head and note the following structures: (a) the large MOUTH with heavy jaws, but no teeth; (b) the pair of dorsal olfactory openings (EXTERNAL NARES); (c) the TYMPANIC MEMBRANE on either side of the head, posterior to the attachment of the lower jaw; (d) the EYES protected by (e) upper and lower EYELIDS and (f) a NICTITATING MEMBRANE which moves laterally to cover the eye. Draw in outline to show general structure.

B. AVES, OR BIRDS

3. Examine a Pigeon and note the general form of this animal and the external covering composed of the unique exoskeletal structures, FEATHERS, which are found only on Birds. Note the division of the body into HEAD, NECK, TRUNK, and short TAIL. Examine the clawed, four-digited HIND LIMBS which are adapted for bipedal locomotion, and the greatly modified FORE LIMBS, or WINGS, which are adapted for flying. Examine the different types of feathers on various regions of the body.

4. Examine the small head, and note the MOUTH with a projecting horny structure (BEAK) which is an anterior continuation of the bony toothless jaws. Identify the OLFACTORY OPENINGS, the AUDITORY OPENINGS, and the EYES with upper and lower EYELIDS and NICTITATING MEMBRANE. Draw in outline to show general structure.

C. MAMMALIA

5. Examine a small Mammal, such as a Rat or a well-developed fetal Pig, and note the general form of this animal covered with the unique exoskeletal material (HAIR) which is found only on Mammals. Note the divisions of the body into HEAD, NECK, TRUNK, and flexible TAIL. Examine the FORE and HIND LIMBS, all of which are adapted for quadrupedal locomotion. Examine the head. Note the MOUTH with well-developed JAWS and TEETH, the OLFACTORY OPENINGS, the AUDITORY OPENINGS with external EARS, the EYES, with upper and lower EYELIDS. Draw in outline to show general structure.

6. Construct a table which will show in a comparative way the chief external structural features of the six Vertebrate types studied in this and the previous exercise.

¹ B. pp. 157-164.

VERTEBRATE EPITHELIAL TISSUES ¹

A. SQUAMOUS EPITHELIUM

1. The flattened, or squamous, type of epithelial cells may be observed in the outer layers of frog skin which are continually being sloughed off. Secure some of this shed tissue unstained. Mount and examine under the microscope. Note the large surface area of these cells as compared with their thickness. Add a few drops of stain, such, for example, as acetic carmine. Reëxamine and note the differentiation of the various cellular structures. Draw to show the structure as observed.

2. This same type of epithelial tissue, but with the cells usually more or less separated from each other, may also be obtained by gently scraping the inside of your cheek with a clean, blunt instrument, such as the handle of your scalpel. Secure some cells in this manner. Mount, stain, and examine as noted above. Draw to show the structure as observed.

B. STRATIFIED EPITHELIUM

3. Examine a prepared, transverse section of frog skin and note that the outer region, or EPIDERMIS, which develops from the ECTODERM, is composed of several layers of epithelial cells, ranging in shape, by gradual transition, from the squamous type on the upper surface, such as was noted in paragraph 1, to the tubular shaped cells of the COLUMNAR epithelium lying next to the DERMIS. Draw to show the different types of epithelial cells observed in the various layers of the epidermis.

C. CILIATED EPITHELIUM

4. Secure a small piece of the living mucous membrane from the roof of the mouth of an anaesthetized Frog. Place the tissue in normal salt solution and tear it apart with dissecting needles in such a way as to secure tiny bits of the lining layer containing numerous ciliated epithelial cells. With a pipette pick up some of these bits of tissue. Mount and examine with low and high power and note the vigorous ciliary action on the outer edge of these cone-shaped cells. Stain the preparation. Re-examine and then draw to show the structure as observed.

D. SECRETORY EPITHELIUM

5. Examine a prepared transverse section of frog intestine under the microscope. Focus on the inner epithelial layer (MUCOSA) which originally develops from the endoderm and which forms the functional digestive and absorptive tissue of the intestine. Study with the high power and note numerous elongated secretory, or glandular, cells which are structurally characterized by the presence of an oval-shaped secreting area near the distal end. Draw a portion of the mucosa showing these cells.

¹ B. pp. 167-169.

VERTEBRATE MUSCLE TISSUES¹

1. **UNSTRIATED MUSCLE.** Examine, with the low and high power, a prepared transverse section of frog **INTESTINE**. Note that it is composed of a number of layers as follows: (a) the thin, outer covering (**PERITONEUM**); (b) the muscular layers consisting of an outer **LONGITUDINAL LAYER** and a thicker, inner **CIRCULAR LAYER**; (c) the connective tissue layer (**SUB-MUCOSA**), and (d) the epithelial layer (**MUCOSA**) which is thrown into folds, and forms the inner lining of the intestine.

2. Study the two layers of unstriated muscle tissue under the high power. Note that the tissue of the **CIRCULAR LAYER** consists of closely packed, elongated, spindle-shaped cells. In the **LONGITUDINAL LAYER** this same type of muscle is also present, but in this case the cells have been cut transversely so that the true shape of the cell bodies is not seen. Draw a portion of both layers to show the structure as observed.

3. Examine a small piece of tissue from the wall of frog intestine or of bladder, which has been properly macerated so as to show the spindle-shaped unstriated muscle cells separated from each other. Note the structure of the individual cells, each with a distinct nucleus and very delicate longitudinal striations. Draw several cells to show structure as observed.

4. **STRIATED MUSCLE.** Place a small piece of fresh muscle from the leg of a Frog in a drop of normal salt solution on a slide. Tear it thoroughly apart with dissecting needles. Add a drop of acetic carmine stain, mount, and examine with the low and the high power. Note that this type of tissue consists of long, striated, cylindrical bundles of **MUSCLE FIBERS** bound together by connective tissue (**PERIMYSIUM**). Under the high power study the cytoplasm (**SARCOPLASM**) of the muscle fibers and observe the distinct **TRANSVERSE STRIATIONS** and the less distinct **LONGITUDINAL STRIATIONS** which are present in them. Each tiny fiber represents a single modified, multinucleate cell with several **NUCLEI** embedded in the sarco-plasm. A very thin layer of connective tissue (**SARCOLEMMMA**) encloses each fiber. Draw to show the structure as observed.

¹ B. pp. 169-172.

VERTEBRATE SUPPORTING TISSUES ¹

1. **FIBROUS CONNECTIVE TISSUE.** Examine, with the high power, a prepared, transverse section of frog skin. Note that: (a) the outer portion (**EPIDERMIS**) of the skin is made up of several layers of stratified **EPITHELIAL CELLS**; (b) the inner portion (**DERMIS**) of the skin is divided into a comparatively loose layer of connective tissue (**STRATUM SPONGIOSUM**) which lies next to the epithelial cells and consists of connective tissue fibers, in which are embedded numerous glands, blood vessels, and lymph spaces. The remainder of the dermis consists of (c) a layer of very dense connective tissue (**STRATUM COMPACTUM**) in which the bundles of wavy connective tissue fibers run, in general, parallel to the surface of the skin. At intervals this layer is crossed by vertical strands which extend through the stratum spongiosum to the epidermis. These strands are made up of connective tissue fibers and also, in some cases, of muscle fibers, nerves, and blood vessels. Draw a portion of the section to show the structure as observed.

2. **CARTILAGE.** Examine, with the high power, a prepared section of **HYALINE CARTILAGE**. Note: (a) the transparent, homogeneous intercellular substance (**MATRIX**) which possesses (b) numerous spaces (**LACUNAE**). The latter contain (c) one or more nucleated **CARTILAGE CELLS**. Note also, in various regions of the preparation, that the lacunae containing the cartilage cells show a tendency to group together. Draw a portion of the section to show the structure as observed.

3. **BONE.** Examine a fresh bone, *e.g.*, the femur of a large mammal, and note its general character and the covering of cartilage at either end where it forms a joint with another bone. Examine a transverse section of a fresh bone and note the outer ring of bony tissue covered by the delicate living **PERIOSTEUM** and enclosing the highly vascular **BONE MARROW**.

4. Examine a permanent microscopic section of stained, decalcified bone. Note (a) the intercellular **MATRIX** arranged in (b) concentric layers (**LAMELLAE**) and containing (c) the cell cavities (**LACUNAE**) in which (d) the bone cells (**OSTEOBLASTS**) lie. Note further (e) the tiny branches (**CANALICULI**) of the lacunae which, in life, contain the delicate projections of the osteoblasts. (f) **HAVERSIAN CANALS** which contain blood vessels may also be identified. Draw to show the structure as observed.

¹ B. pp. 172-175.

AXIAL SKELETON ¹

1. Examine the SKULL of a Dog or Cat. Note that it consists of the BRAIN CASE (CRANIUM), and the FACIAL PORTION which forms the framework of the face and jaws. Locate the bony SENSE CAPSULES which enclose and protect the nose, eyes, and ears. Observe the articulation of the lower jaw (MANDIBLES) at the posterior end of the skull with the posterior portion of the prominent ZYGOMATIC ARCH. Note the similarity and the relation of the TEETH of both jaws and their adaptation for different purposes. Various openings (FORAMINA) are present in the skull bones, which serve as exits for the cranial nerves and blood vessels. The largest of these is the FORAMEN MAGNUM at the posterior end of the skull, through which the spinal cord passes into the cranium. On each side of the foramen magnum is a smooth, rounded prominence (OCCIPITAL CONDYLE). The condyles fit into depressions on the first vertebra of the vertebral column, and thus articulate the skull with it.

2. Examine the surface of the skull and note that it is composed of a considerable number of bones which are jointed together by irregular SUTURES. Identify the following bones: (a) the OCCIPITALS, which form the posterior part of the skull around the foramen magnum; (b) the PARIETALS, which form a considerable portion of the dorsal and lateral walls of the cranium; (c) the TEMPORALS, in which the ears are located, consist chiefly of the dorsal SQUAMOSAL portions and lie ventral to the parietals. From each of them there is (d) a curved projection (ZYGOMATIC PROCESS) which unites anteriorly with (e) the MALAR bone to form the ZYGOMATIC ARCH; (f) the FRONTALS which lie anterior, to parietals and dorsal to the eye; (g) the median NASALS which form the dorsal wall of the nasal cavity; (h) the MAXILLAE and (i) the small PREMAXILLAE, which together form the upper jaw and a large portion of the roof of the mouth; (j) the PALATINES which lie in the roof of the mouth posterior to the maxillary bones; (k) the median SPHENIDS, posterior to the palatines; and (l) the MANDIBLE, or lower jaw.

3. Draw the skull from the left side, showing as many as possible of the parts mentioned above.

4. Examine a VERTEBRA from either the thoracic or lumbar region of the spinal column. Note: (a) the large, solid CENTRUM, with (b) the NEURAL ARCH lying dorsal and surrounding (c) the NEURAL CANAL; (d) the TRANSVERSE PROCESSES for the attachment of muscles, projecting laterally from each side; (e) the NEURAL SPINE, which projects dorsally from the neural arch, and (f) the ANTERIOR and POSTERIOR ARTICULAR PROCESSES. Draw the vertebra from either an end or a side view.

¹ B. pp. 175-179.

APPENDICULAR SKELETON ¹

1. With the structural plan of the vertebrate pentadactyl limb in mind, examine the mounted skeleton of a Dog or Cat and note the differences between the fore limbs and the hind limbs, as well as between their respective girdles.

2. Secure a detached fore limb and determine from the mounted skeleton whether it is a right limb or a left limb. Identify the following bones: (a) the shoulder blade (SCAPULA) with a median ridge; (b) the large HUMERUS; (c) the RADIUS, and (d) ULNA — the latter is the larger and forms the main articulation with the humerus; (e) the WRIST (CARPUS), composed of seven CARPAL bones; (f) the HAND, composed of five METACARPAL bones and five DIGITS. Each of the digits consists of three bones (PHALANGES) with the exception of the first, corresponding to our thumb, which has only two. Make a reduced drawing of the entire fore limb.

3. Secure a detached hind limb and determine from the mounted skeleton whether it is a right limb or a left limb. Identify the following bones: (a) the PELVIS, which has a bony attachment to the vertebral column; (b) the large FEMUR; (c) TIBIA, and (d) FIBULA — the former is the larger and forms the main articulation with the femur; (e) the ANKLE (TARSUS), composed of seven TARSAL bones; (f) the FOOT, composed of five METATARSAL bones, one of which is much reduced, and four digits — the first is lacking — each of which consists of three bones (PHALANGES). Make a reduced drawing of the entire hind limb.

4. For comparison, study the limbs of a Bird, Bat, Horse, and Man. Note, in all these types, the homologies of the principal bones and their modifications, such as changes in form, consolidation, suppression, etc.

¹ B. pp. 179-181.

VISCERA OF THE FROG ¹

1. Pin out a freshly chloroformed Frog, with the ventral surface up, in a dissecting tray. With fine forceps lift up the loose skin near the posterior end of the abdomen, and then with scissors make a longitudinal incision, through the skin only, just to one side of the median line and running from the posterior end of the abdomen to the throat region. Make a transverse incision in the skin in the pelvic region, and also one just posterior to the fore limbs. Pin out the flap of skin on each side.

2. In the same way make a longitudinal cut through the muscle tissue of the body wall, running from the pelvic region to the sternum. Cut through the bony shoulder girdle on each side of the sternum, being *careful* not to injure the underlying heart. Make transverse cuts as before and pin the flap of body wall on each side over the flap of skin previously pinned out.

3. Examine the large coelom filled with the VISCERA, which you have now exposed. It is lined with a delicate membrane (PERITONEUM) which is continuous over the various organs in the body cavity. The peritoneum also forms folds (MESENTERIES) by which certain organs are suspended and held in place. Identify and study the following structures:

(a) The HEART, at the anterior end of the coelom, enclosed in a delicate, transparent sac (PERICARDIUM). Carefully remove the pericardium. Watch the pulsations of the heart and determine the number per minute. Place your finger tip on the heart while it is beating and note the alternate tension and relaxation. Locate: (i) the single, thick-walled posterior VENTRICLE; (ii) the pair of thin-walled anterior AURICLES; and (iii) the CONUS ARTERIOSUS which leads anteriorly from the ventricle. Lift the heart and locate, underneath, the SINUS VENOSUS which opens into the right auricle.

(b) The LUNGS, consisting of a pair of thin-walled vascular sacs which communicate to the exterior through the glottis in the mouth. The lungs lie close to the dorsal body wall on each side, near the heart.

(c) The LIVER, consisting of three large, reddish-brown lobes which lie in a prominent position lateral and posterior to the heart. Separate the lobes slightly and find the GALL BLADDER, which receives BILE from each of the lobes.

¹ B. pp. 181-184.

(d) The ALIMENTARY CANAL, consisting of a long tube running from the mouth to the cloaca. Identify the sac-like STOMACH which lies to the animal's left, just under the tips of the lobes of the liver, and the coiled SMALL INTESTINE, which can be traced posteriorly to the LARGE INTESTINE. Note the small, spherical, red SPLEEN nearby.

(e) The UROGENITAL ORGANS, consisting of the KIDNEYS and either the male gonads (TESTES) or female gonads (OVARIES). These lie close to the dorsal body wall, and can be seen by gently pushing the intestine slightly to one side. In the spring, the abdominal cavity of the female is largely filled with the developing eggs in the right and left ovaries.

(f) Arrange the organs to the best advantage, and make a full page drawing to show as many as possible of the observed structures.

BUCCAL CAVITY AND RESPIRATORY ORGANS¹

1. Pin the Frog which you previously dissected, ventral surface up, in a dissecting pan. Pull back the lower jaw, cutting a little at each corner, and then pin the edge of the lower jaw to the ventral surface of the body so as to expose fully the cavity of the mouth (BUCCAL CAVITY).

2. Note the upper jaw with (a) a projecting, fleshy upper lip, and bearing (b) numerous very fine MAXILLARY TEETH, which you can feel by rubbing over them with your finger; (c) the two groups of VOMERINE teeth on the dorsal roof of the mouth; (d) the olfactory openings (INTERNAL NARES), one on either side of the vomerine teeth; (e) the openings of the EUSTACHIAN TUBES, posterior to the internal nares.

3. Note the lower jaw with (a) the muscular TONGUE, which is attached anteriorly, and (b) the circular elevation with a median, slit-like opening (GLOTTIS) into the TRACHEAL CAVITY which leads to the lungs. Leading from the posterior end of the mouth is (c) the ESOPHAGUS which continues to the stomach. Make a drawing of the entire mouth cavity to show the structures observed.

4. Place the lower jaw in a normal position and then carefully remove the skin from the ventral surface of the body, anterior to the fore limbs. Carefully cut the connecting blood vessels, and remove the heart from the body. Locate the lungs which you saw in a previous exercise and trace each one to the thin walled tracheal cavity which lies just ventral to the glottis, as noted in paragraph 3. Now remove the lungs, tracheal cavity, and glottis, after having carefully cut around the glottis with the scissors, and pin them out in a dissecting pan. With fine scissors, make a median longitudinal cut through the ventral wall of each lung and continue each cut into the tracheal cavity. Pin back the cut surfaces so as to expose the interior of the various structures. Note: (a) the structure of the lungs; (b) the structure of the tracheal cavity, with (c) the pair of VOCAL CORDS lying on each side. Draw to show the structure as observed.

5. Study a model of a median longitudinal section of a human head and neck, showing the MOUTH, or BUCCAL CAVITY, and the THROAT CAVITY, or PHARYNX. Note that the mouth cavity is bounded dorsally by (a) a bony partition (HARD PALATE) which separates it from (b) the NASAL CAVITY above. The hard palate extends posteriorly and merges into (c) the SOFT PALATE which partially separates the mouth cavity from the pharynx. On each side the mouth cavity is enclosed by the cheeks and by the jaws bearing teeth. Below, the mouth cavity is bounded by (d) the thick muscular TONGUE. Note further that both the nasal cavity and the buccal cavity open into the pharynx through which both the food and the air pass. Then the trachea, protected by the epiglottis, branches off to the lungs, and the esophagus continues to the stomach. (W. f. 109.)

¹ B. pp. 189-192.

ALIMENTARY CANAL AND ASSOCIATED ORGANS OF THE FROG ¹

1. Secure the specimen previously dissected. Cut off and discard the portion of the lower jaw which lies anterior to the glottis. Next cut through the mucous membrane lining the dorsal part of the mouth cavity, just posterior to the openings of the Eustachian tubes. Be careful not to disturb the underlying bony structures of the upper jaw. You have now freed the anterior end of the esophagus from the body.

2. With your forceps, gently lift up the lower jaw with the attached esophagus and then, beginning anteriorly, carefully cut all the mesenteries which attach the alimentary canal to the body. Make a transverse cut through the anterior end of the rectum. Now remove the entire alimentary canal with the attached liver and pancreas from the body, taking care not to disturb the underlying urogenital organs. Place the organs which you have just removed in a dissecting pan and pin them out so as to show to the best advantage. It may be necessary to cut some of the mesenteries.

3. Examine the alimentary canal throughout its entire length. Identify and note the structure of the (a) ESOPHAGUS; (b) STOMACH; (c) PYLORIC VALVE; (d) SMALL INTESTINE; (e) PANCREAS with the PANCREATIC DUCT, which joins the BILE DUCT from the gall bladder of the liver before the latter opens into the small intestine; and (f) the LARGE INTESTINE, which merges into the cloaca. Draw to show the various structures as observed.

4. Examine, with the low and high power, a prepared transverse section of Frog INTESTINE. Note that it is composed of a number of layers as follows: (a) the thin, outer covering (Serosa); (b) the muscular layers consisting of an outer LONGITUDINAL LAYER and a thicker, inner CIRCULAR LAYER; (c) the connective tissue layer (SUBMUCOSA), and (d) the epithelial layer (MUCOSA) which is thrown into folds, and forms the inner lining of the intestine. The mucosa consists of two types of elongated epithelial cells, namely, the ABSORPTIVE CELLS, and the SECRETORY CELLS, or UNICELLULAR GLANDS. The latter type may be distinguished by the presence of a secreting area in each. Draw the section in outline and fill in a portion to show the detailed structure of the various layers.

¹ B. pp. 184-189.

VASCULAR SYSTEM OF THE FROG¹

1. Secure a specimen, with the blood vessels injected, and fasten it ventral surface up in a dissecting pan. Expose the HEART and identify the major divisions (AURICLES, VENTRICLE, SINUS VENOSUS, CONUS ARTERIOSUS). Trace the conus arteriosus leading from the ventricle and note that, just anterior to the auricles of the heart, it divides into two branches from each of which three arteries arise. Identify these arteries arising from the *right* branch of the conus arteriosus as follows: (a) the PULMOCUTANEOUS artery, which arises nearest the heart and runs to the skin and lungs; (b) the SYSTEMIC ARCH which runs laterally and dorsally and unites with the left systemic arch to form the large (c) DORSAL AORTA noted in paragraph 2 below; (d) the COMMON CAROTID artery which shortly branches to form (e) an INTERNAL CAROTID and (f) an EXTERNAL CAROTID. These vessels supply the entire head region with arterial blood.

2. Note the location of these same arteries as they arise from the *left* branch of the conus arteriosus, and then trace the right and left systemic arches laterally and dorsally to where they unite, posterior to the heart and close to the dorsal body wall, to form the DORSAL AORTA. Just previous to their union each systemic arch gives rise to (a) the OCCIPITO-VERTEBRAL artery which runs to the jaws, nasal region, and vertebral column and (b) to the BRACHIAL artery running to the fore limbs and nearby body wall.

3. Trace the dorsal aorta posteriorly, noting a number of important branches which supply the alimentary canal and associated structures, urogenital system and nearby body wall. Trace the aorta to the posterior part of the abdominal cavity and note its division into the right and left ILIAC arteries which, after branching to form several small vessels, continue posteriorly out of the body cavity and into each of the hind limbs.

4. Make a drawing to show the heart and the arterial system as observed in the previous paragraphs.

5. It will not be profitable to trace the vessels of the venous system which return the blood to the heart and which run parallel, in most cases, to the vessels of the arterial system, but the complete course of the circulation of the blood through the body should be understood and diagrammed.

6. Observe under the microscope the circulation of the blood as seen in the living interdigital web of the Frog's foot. In a favorable area note (a) the larger arterial vessels, with a comparatively rapid pulsating blood flow which results from the change in pressure due to the contractions of the ventricle; (b) the tiny CAPILLARIES which form a connecting link between the arteries and veins. Their diameter is, in many cases, sufficient only to permit the passage of (c) the red blood CORPUSCLES in single file. The capillaries in turn connect with (d) the VEINS which carry the blood in a slow-moving, regular-flowing stream towards the heart.

¹ B. pp. 192-201.

HEART OF THE MAMMAL ¹

1. Examine a Pig's heart and note that it is conical in form, with a broad base and a narrow apex. Place it with the apex pointing toward you and note the following external features: (a) the LEFT VENTRICLE, with very thick, muscular walls, continuing to the tip of the apex; (b) the RIGHT VENTRICLE, with thinner walls, lying beside the left ventricle except near the tip, which is entirely formed by the left ventricle; (c) the LEFT AURICLE; and (d) the RIGHT AURICLE, both lying anterior to the ventricles. Both of the auricles are smaller and have much thinner walls than the ventricles, and each is provided with (e) an ear-like flap of tissue (AURICULAR APPENDAGE).

2. Explore the cavity ² of the left auricle, noting (a) the openings of the PULMONARY VEINS, and (b) the opening into the LEFT VENTRICLE.

3. Explore the cavity of the left ventricle, noting: (a) the very heavy, MUSCULAR WALLS; (b) the MITRAL VALVE, guarding the opening from the auricle, the edges of which are attached to (c) elevations (PAPILLARY MUSCLES) of the muscular walls of the ventricle by a number of (d) fine tendinous cords (CHORDAE TENDINEAE). Feel with your finger and find (e) the opening into the AORTA. Study the aorta, noting (f) its heavy, elastic walls; (g) the SEMILUNAR VALVES; and (h) the opening of the CORONARY ARTERY just beyond the valves.

4. Explore the cavity of the right auricle, noting (a) the large openings from the VENAE CAVAE; (b) the small opening of the CORONARY VEIN just posterior to the former; and (c) the opening into the RIGHT VENTRICLE.

5. Explore the cavity of the right ventricle, noting (a) the thinness of the walls as compared with the left ventricle; (b) the TRICUSPID VALVE which shows the same structure as the mitral valve. Find the opening into (c) the PULMONARY ARTERY, which contains (d) SEMILUNAR VALVES, the same as in the aorta.

6. Make a drawing of the heart from the left side, showing as many as possible of the observed structures.

¹ B. pp. 193-194.

² The various chambers of the heart should be opened by making a longitudinal incision through the walls.

VERTEBRATE KIDNEY¹

1. Examine half of a Pig's kidney. Observe that it is somewhat bean-shaped in outline, with a marked depression (HILUS) on one edge, in which region the ureter arises. Examine the cut surface of your specimen and note that three regions of the kidney can be distinguished as follows: (a) an outer, darker area (CORTEX) containing great numbers of the microscopic, functional elements (MALPIGHIAN BODIES); (b) an inner, striated medullary portion (MEDULLA) containing the URINIFEROUS TUBULES, and (c) the PELVIS, which is really the expanded end of the ureter. The uriniferous tubules of the medulla open into the pelvis at the tips of the conical-shaped projections (PYRAMIDS OF MALPIGHI), and the latter are separated from each other by prolongations of the cortex into the pelvis. Make a drawing of the cut surface of the kidney to show the structure as observed.

2. Examine, with the low and the high power, a prepared section of a Frog's kidney and note the general arrangement, consisting of a comparatively thin area on one side which contains a number of rounded MALPIGHIAN BODIES, and a thicker area filled with the URINIFEROUS TUBULES which have been sectioned in various planes. Make a drawing to show the general arrangement.

3. Select a single Malpighian body and focus on it with high power. It consists of (a) a spherical knot of fine blood vessels (GLOMERULUS) containing numerous red blood corpuscles which appear yellow in the preparation, and (b) a definite, surrounding membrane (BOWMAN'S CAPSULE) which is essentially the enlarged and highly differentiated end of a URINIFEROUS TUBULE. Focus on a portion of one of the uriniferous tubules and note the cellular wall and central LUMEN. Make a drawing of a Malpighian body and of a portion of a uriniferous tubule.

¹ B. pp. 201-204.

UROGENITAL SYSTEM OF THE FROG ¹

1. Pin the specimen ² — from which you have previously removed the alimentary canal and associated organs — in a dissecting pan, ventral surface up as before. Carefully cut through the bony pelvis in the median line and thus completely expose the CLOACA, into which the rectum and the ducts from the urinary and genital organs empty, and, on the ventral surface of which, the thin-walled, bilobed BLADDER opens.

2. FEMALE FROG. In the spring, the right and left ovaries become greatly distended and fill a large portion of the body cavity. Separate the ovaries and push them to either side so that the other organs may be seen to advantage. Note: (a) a pair of reddish, flattened, oval-shaped KIDNEYS, close to the dorsal body wall; (b) a pair of elongated, orange-colored ADRENAL BODIES, one lying on the ventral surface of each kidney; (c) a pair of yellowish FAT BODIES with long finger-like processes; (d) a pair of long, coiled OVIDUCTS which open anteriorly into the body cavity near the base of each lung. Posteriorly, before opening into the cloaca, each of the oviducts enlarges to form (e) a thin-walled UTERUS. Examine the outer margin of the kidneys and find on each (f) a URETER, which can be traced posteriorly to its opening in the cloaca. Note also the BLOOD VESSELS which supply the kidneys. Make an enlarged drawing to show the structures observed.

3. MALE FROG. Locate and examine the following parts of the male urogenital system: (a) a pair of reddish, flattened, oval-shaped KIDNEYS, close to the dorsal body wall; (b) a pair of white TESTES attached to the kidneys by a number of fine ducts (VASA EFFERENTIA); (c) a pair of elongated, orange-colored ADRENAL BODIES, one lying on the ventral surface of each kidney; (d) a pair of yellowish FAT BODIES with long finger-like processes; (e) in many specimens a pair of small, coiled RUDIMENTARY OVIDUCTS are to be found situated laterally to the kidneys. Examine the outer margin of the kidneys and find (f) the UROGENITAL CANALS, each of which can be traced posteriorly to its opening in the cloaca. Note also the BLOOD VESSELS attached to the kidneys. Make an enlarged drawing to show the structures observed.

¹ B. pp. 204-206.

² Better results will be obtained by using a fresh specimen for this exercise

SPINAL NERVES OF THE FROG ¹

1. Pin your specimen in the dissecting pan as before. Remove any of the viscera which may be present in the body cavity. Examine the dorsal wall of the body cavity and note the paired SPINAL NERVES which may be seen as small, white cords running laterally from either side of the vertebral column. They arise in the spinal cord and emerge from between the vertebrae through the light-colored CALCAREOUS BODIES.

2. Beginning at the anterior end, identify and trace the ten pairs of spinal nerves as follows :

(1) A small pair which emerges from between the first and second vertebrae just anterior to the fore limbs, usually giving off a small branch to the second nerve before continuing laterally into the muscles.

(2) A large pair which supplies the fore limbs after usually having received branches from the first and third pairs. This union forms the BRACHIAL PLEXUS.

(3) A small pair which, after giving off a branch to the second pair for the brachial plexus, can be traced laterally into the muscles.

(4), (5), and (6) are small pairs which can be traced into the muscles of the body wall.

(7), (8), and (9) are larger pairs which run almost directly posteriorly and anastomose to form the SCIATIC PLEXUS, from which arises the large SCIATIC nerve. By careful dissection, follow the sciatic nerve from the plexus down through the leg, noting the various branches which are given off. Note also a branch of the seventh nerve, which is given off anterior to the sciatic plexus.

(10) A small pair, each of which emerges from openings near the anterior end of the urostyle and supplies chiefly the urogenital organs.

3. Note the two small, ganglionated chains of the AUTONOMIC NERVOUS SYSTEM ; one lying on either side of the mid-dorsal line. Note the attachment by a fine nerve fiber to each of the spinal nerves.

4. Make a drawing to show the location and course of the spinal nerves and the autonomic chains.

¹ B. pp. 213-215.

CENTRAL NERVOUS SYSTEM OF THE FROG ¹ (1)

1. Secure your dissected Frog and carefully remove the skin from all parts of the body. Fasten the specimen, dorsal surface up, in a dissecting pan and then with a sharp, pointed scalpel, pick off, bit by bit, the bony roof of the skull in the region between the eyes, taking great care not to injure the brain underneath by inserting the scalpel too deeply. Small pieces of the bone may also be snapped off with the tips of the scissors. Continue the area of dissection anteriorly to the nasal region and posteriorly to the end of the skull, thus entirely exposing the dorsal surface of the brain. Note that it is covered by a thin pigmented membrane (DURA MATER) which should be carefully removed with fine forceps.

2. Examine the brain from the dorsal surface and, beginning at the anterior end, note the following parts: (a) the fused OLFACTORY LOBES, from which the OLFACTORY NERVES may be seen extending anteriorly to the nasal region; (b) the pair of CEREBRAL HEMISPHERES which merge anteriorly into the olfactory lobes; (c) an unpaired portion (DIENCEPHALON) bearing (d) a small, median structure (PINEAL BODY); (e) a pair of egg-shaped OPTIC LOBES, back of which is (f) a transverse elevation (CEREBELLUM), and, posterior to the cerebellum, (g) the MEDULLA OBLONGATA, which appears as the enlarged anterior end of the spinal cord and contains (h) a triangular depression, the FOURTH VENTRICLE. The FORE-BRAIN consists of the olfactory lobes, cerebral hemispheres, and diencephalon; the MID-BRAIN, as seen from the dorsal surface, of the optic lobes; and the HIND-BRAIN, of the cerebellum and medulla oblongata.

3. Make a drawing at least twice natural size to show the dorsal surface of the brain in its normal position.

¹ B. pp. 206-213.

CENTRAL NERVOUS SYSTEM OF THE FROG ¹ (2)

1. Continue the dissection of the central nervous system by very carefully removing, with the tips of the scissors, the bony, dorsal arches of all the vertebrae, thus exposing the SPINAL CORD throughout its entire length.

2. The brain and spinal cord should now be removed from the animal. In order to do this it will be necessary to cut the cranial and spinal nerves which run from the central nervous system to the various regions of the body. Begin at the anterior end of the brain and cut the olfactory nerves first. Then carefully raise the anterior end of the brain, note the large OPTIC NERVES on the ventral surface anterior to the optic lobes, and cut them. Continue posteriorly in this manner, and when the entire central nervous system is free, remove it and place in a small dish of water for further study.

3. Study the ventral surface of the brain under the dissecting microscope and locate the regions of the fore-brain, mid-brain, and hind-brain. Note: (a) the origin of the OLFACTORY NERVES; (b) the origin of the OPTIC NERVES and the crossing of the fibers of each in the mid-ventral line under the optic lobes, to form (c) the OPTIC CHIASMA; (d) the heart-shaped INFUNDIBULUM which lies underneath the optic chiasma, and (e) the HYPOPHYSIS lying posterior to the infundibulum. The latter is frequently detached from the brain when removing it from the brain case. The infundibulum and hypophysis constitute the PITUITARY BODY—an important endocrine organ.

4. Study the spinal cord and note: (a) the enlargement in the brachial region where the nerve supply of the fore limbs arises; (b) the enlargement in the pelvic region where the nerve supply of the hind limbs arises; and (c) the small terminal portion (FILUM TERMINALE).

5. Make a drawing of the ventral surface of the brain and spinal cord at least twice natural size, showing all the structures observed.

¹ B. pp. 206-213.

BRAIN OF THE MAMMAL ¹

1. Examine the dorsal surface of a Sheep's brain. Note the large anterior CEREBRUM, which consists of a right and left CEREBRAL HEMISPHERE. Posterior to the latter is the median, unpaired CEREBELLUM, lying above the MEDULLA which merges into the SPINAL CORD. The brain is enclosed in three membranes: (a) the DURA MATER, which lines the interior of the skull; (b) the ARACHNOID, which is the membrane you see, and (c) the PIA MATER, which lies below the arachnoid and is very closely applied to the brain tissue. Note that the outer surface of the cerebrum (CEREBRAL CORTEX) is arranged in ridges (GYRI), between which are depressions (SULCI) of varying depths.

2. Examine the ventral surface of your specimen. Note: (a) the CEREBRAL HEMISPHERES; (b) the OLFACTORY LOBES (often destroyed in removing the brain from the skull), from each of which (c) olfactory nerve fibers arise; (d) the OPTIC CHIASMA, from which (e) the OPTIC NERVES arise; (f) the PITUITARY BODY, under and posterior to the optic chiasma, and lying on (g) the thickened, ventral wall (CRURA CEREBRI) of the mid-brain; (h) the prominent, transverse band of fibers (PONS VAROLII) with (i) a root of the important fifth cranial nerve (TRIGEMINAL) arising just posterior and on each side; (j) the eighth cranial nerves (AUDITORY) which arise close to the ventral edge of the cerebellum just posterior to the fifth cranial nerve. Make a drawing from the ventral surface to show the structures as observed.

3. Examine the cut surface of a brain which has been sectioned in a median longitudinal plane. Note the general arrangement and the large CEREBRAL HEMISPHERE which lies anterior and dorsal to the mid-brain. Identify the following structures in addition to those noted above: (a) the CORPUS CALLOSUM, which consists of a fibrous plate connecting the two cerebral hemispheres; (b) the CORPORA QUADRIGEMINA, which lie just anterior to the cerebellum and constitute the dorsal wall of the mid-brain; (c) the small spherical PINEAL BODY lying in an indentation anterior to the corpora quadrigemina; and (d) the cavity (FOURTH VENTRICLE) in the medulla, lying underneath the cerebellum.

4. Make a drawing of the half-brain from the cut surface, showing as many as possible of the structures which you have found in the preceding paragraphs.

¹ B. pp. 209-211; 220-221.

HISTOLOGY OF NERVE TISSUE¹

1. Examine, with the low and with the high power, a prepared transverse section through the SPINAL CORD of the Frog or other Vertebrate. Note: (a) the thin, outer covering (DURA MATER); (b) the rather shallow indentation on the dorsal side (DORSAL FISSURE); (c) the deeper indentation on the ventral side (VENTRAL FISSURE); (d) the outer layer (WHITE MATTER) largely composed of nerve fibers, and less compact than (e) the inner material of the cord (GRAY MATTER) which contains (f) a large number of nerve cells, or NEURONS. In the center of the cord is (g) the small cavity (CENTRAL CANAL) which runs the entire length of the spinal cord. If the section happens to pass through a spinal nerve, the (h) DORSAL and VENTRAL ROOTS may be seen connected with the gray matter. Make a drawing of the section to show the structures as observed.

2. Using the high power, focus directly on the large, irregularly shaped MOTOR NERVE CELLS in the ventral portion of the gray matter on either side of the cord. Note the large NUCLEUS in each cell and the FIBRILLATED CYTOPLASM. Try to find a nerve cell which has been sectioned so that it shows the long nerve process (AXON) leading from it. Draw one of the motor nerve cells, showing all details of structure as observed.

3. Secure a small piece of a fresh nerve taken from an anaesthetized Frog, place it on a slide in a drop or two of normal salt solution, and tear it apart with dissecting needles. Mount and examine under the microscope. Note that the nerve is composed of a number of fine, thread-like fibers, each of which consists of (a) a delicate, external membrane (NEURILEMMA), (b) a thicker insulating layer (MEDULLARY SHEATH), and (c) the central nerve fiber, or AXON, which, as noted above, is a direct continuation of the cytoplasm of a nerve cell. At intervals along each fiber, there are breaks in the medullary sheath (NODES OF RANVIER), but the neurilemma and the axon are continuous. Draw to show the structure as observed.

¹ B. pp. 214-215.

VERTEBRATE EYE ¹

1. Place a dissecting microscope on its side in front of you and turn the mirror in such a position that you can examine your own eye. Make a drawing, showing (a) the EYELIDS; (b) the white of the eye (SCLEROTIC COAT) which in front forms (c) the transparent CORNEA; (d) the underlying colored portion (IRIS) with (e) a circular, central opening (PUPIL).

2. Examine the eye of a Pig or Sheep, which has been removed from its orbit. Note: (a) the shape; (b) the character of the outer, protective covering (SCLEROTIC COAT); (c) the attachment of the muscles; and (d) the OPTIC NERVE.

3. For details of the internal anatomy, examine an eye which has been cut in half and find the following structures: (a) the SCLEROTIC COAT, a comparatively thick layer of connective tissue, which, in the front of the eye, forms (b) the transparent CORNEA; (c) the CHOROID COAT, a thin, deeply pigmented, vascular layer which, in the front of the eye, forms (d) the colored IRIS, in the center of which is (e) the circular opening (PUPIL); (f) the transparent LENS, which lies just posterior to the iris; and (g) the sensory layer, or RETINA, which is directly continuous with (h) the OPTIC NERVE, running from the posterior part of the eye to the brain.

4. Note the following chambers of the eye: (a) the ANTERIOR CHAMBER, situated between the cornea and iris; (b) the small POSTERIOR CHAMBER, situated between the iris and lens and communicating with the anterior chamber through the pupil; and (c) the large VITREOUS CHAMBER posterior to the lens, in which the retina lies. The vitreous chamber is filled with a transparent, jelly-like material (VITREOUS HUMOR). The two chambers in front contain a more fluid substance (AQUEOUS HUMOR).

5. Make a drawing, about three inches in diameter, showing the structures as observed.

¹ B. pp. 215-220.

SPERMATOGENESIS ¹

1. Examine, with the low and the high power, a prepared section of mouse **TESTIS**. Note that it consists of a great number of tubules (**SEMINIFEROUS TUBULES**) in the walls of which the **SPERM CELLS** develop. The tubules are greatly convoluted, and consequently, in the preparation, they are sectioned in various planes. At one side of the testis a section of the **EPIDIDYMIS** may be seen. This is the conducting tube that carries the mature sperm from the testis. It corresponds, in general, to the vasa efferentia of the Frog testis (as noted on page 339). Draw the entire testis in outline and fill in a portion with careful detail.

2. Select a seminiferous tubule which has been sectioned approximately transversely and study with the high power. Note the arrangement, size, and structure of the **SPERMATOGONIA**, **SPERMATOCYTES**, **SPERMATIDS**, and mature **SPERM**. Draw the entire tubule in outline and fill in a portion, showing, with careful detail, the germinal cells in various stages of maturation.

3. Examine the epididymis under high power. Note that the tubules are filled with mature sperm. Draw a tubule to show the structure as observed.

¹ B. pp. 204-205.

OÖGENESIS ¹

1. Examine a fresh ovary of a pig and note the numerous more or less transparent prominences (GRAAFIAN FOLLICLES) of various sizes in which the egg cells develop. The more mature follicles are larger and more transparent. Note also the hard, yellowish substance (CORPORA LUTEA) with which the cavity of a follicle is filled after the mature egg has been discharged. Make an enlarged drawing of the entire ovary to show the structure as observed.

2. Examine, with the low power, a prepared section of a mouse ovary. Note the outer covering (GERMINAL EPITHELIUM) in which the eggs are first formed and from which they move into the body of the ovary, where they become surrounded by FOLLICLE CELLS, and thus form the GRAAFIAN FOLLICLES. The latter can be seen in various stages of development. In the immature follicles the large central EGG is closely surrounded by several layers of the follicle cells. In the larger, more mature follicles, a liquid-filled cavity develops around the egg. In close contact to the egg are a few layers of the follicle cells which also support it at one point. Areas of the yellowish corpora lutea can also be seen in the preparation. The ground substance of the ovary consists of connective tissue with the numerous cells and blood vessels embedded in it. Draw the entire ovary in outline and fill in a portion to show the structure as observed.

3. Select the most mature follicle containing an egg with nucleus which your preparation shows. Study it carefully with the high power and draw the entire follicle in detail.

¹ B. pp. 205-206.

FERTILIZATION AND MITOSIS¹

1. Examine, with the low and the high power, a prepared transverse section of the uterus of *Ascaris*. Note the heavy UTERINE WALL and the central LUMEN containing many thick-shelled EGGS which are in various stages of MITOSIS. Draw the entire section of the uterus in outline and then fill in a sector to show the details.

2. Study the preparation with the high power. Identify eggs in the following stages of fertilization and mitosis and make a drawing of each stage about two inches in diameter:

(a) CONTACT and FUSION of the male and female GAMETIC NUCLEI, which constitutes the essential feature of FERTILIZATION, and is followed by the various stages of MITOSIS.

(b) EARLY PROPHASE, with the chromatin in each gametic nucleus in the form of a long thread (SPIREME), and the centrosomes at opposite poles of the fusion nucleus (SYNKARYON).

(c) LATE PROPHASE, with the chromatin in the form of definite CHROMOSOMES, the nuclear membranes broken down, and the SPINDLE well-developed.

(d) METAPHASE, with the chromosomes divided in the equatorial plate; or the slightly later ANAPHASE, with the chromosomes leaving the equatorial plate and moving along the spindle fibers toward the centrosomes.

(e) TELOPHASE, with the spindle breaking down and the cytoplasm of the cell dividing to form two cells.

Label in each of the above stages where present: EGG SHELL, CYTOPLASM, CENTROSOMES, ASTERS, SPINDLE FIBERS, and CHROMATIN, or CHROMOSOMES.

3. The process of mitosis may also be studied in permanent preparations of the Onion root tip (page 247) which have been properly stained. Study the stages corresponding to those described under (b), (c), (d), and (e) of the preceding paragraph and make a series of drawings which will show all details of the process which you have been able to observe.

¹ B. pp. 222-223.

DEVELOPMENT OF THE FROG¹ (1)

1. Place an unsegmented Frog's egg in a watch glass containing water and examine it with both the dissecting microscope and the low power of the compound microscope. Note that the egg is enclosed in a transparent jelly, and that it consists of a dark-colored portion (ANIMAL POLE), which tends to lie uppermost in the water, and a lighter-colored portion (VEGETAL POLE). Make a drawing of the egg from the side, one inch in diameter, so as to show both poles and the surrounding layer of jelly.

2. Examine, in the same way, the following cleavage stages of Frog's eggs: 2-4 cells, 8 cells, 20-30 cells, and many cells, or BLASTULA. Note in each stage the direction of the cleavage planes and the comparative size of the cells in the animal and vegetal poles. Make a drawing of each stage from the side, omitting the jelly.

3. Examine, as before, a Frog's egg in which the growth of the dark cells of the animal pole over the light cells of the vegetal pole has begun (GASTRULA). As this process of gastrulation continues, the circular area (BLASTOPORE) at the vegetal pole becomes smaller. Finally, when gastrulation is complete, the blastopore is very small, and only a tiny portion of the cells of the vegetal pole is visible externally, which is known as the YOLK PLUG. Draw the gastrula from the vegetal pole, showing the yolk plug.

¹ B. pp. 222-225.

DEVELOPMENT OF THE FROG¹ (2)

4. Examine, in a watch glass of water as before, a later stage in the development of the Frog in which the body of the animal has begun to elongate in an anteroposterior direction. Note that the **BLASTOPORE**, which was circular, has now become a slit-like opening which marks the posterior end of the embryo. Note also the dorsal, longitudinal groove (**NEURAL GROOVE**) which indicates the position of the future central nervous system. Draw the embryo from the posterior end.

5. Examine, as before, still later developmental stages as follows: (a) an embryo in which the **HEAD** and **TAIL** have just become differentiated; (b) an embryo with well-developed external **GILLS**; (c) a fully formed, free-swimming **TADPOLE**, in which the external gills have become covered by the **OPERCULUM**, leaving only a small opening (**SPIRACLE**) on the left side of the animal in the gill region; (d) an embryo in an early stage of metamorphosis, showing a single pair of small hind legs, and (e) an embryo in a late stage of metamorphosis, with both pairs of legs present and the tail in process of absorption. Draw each of these embryos from the left side and label in each stage, where developed: **NOSE**, **EYE**, **MOUTH**, **SUCKER**, **GILLS**, **OPERCULUM**, **MUSCLE PLATES**, **BLASTOPORE**, **ANUS**, and **TAIL**.

¹ B. pp. 225-232.



DEVELOPMENT OF THE CHICK¹ (1)

1. Examine, with the dissecting microscope and with the low power of the compound microscope, a permanently mounted three-day Chick embryo. Note that the general shape resembles a 'reversed question-mark' with the head end turned toward the right. Anteriorly, the embryo is lying on its left side and, posteriorly, on its ventral surface. On each side of the embryo, note the VASCULAR AREA with the large vessels (VITELLINE ARTERIES and VITELLINE VEINS) which enter the embryo near the middle of the body.

2. Beginning at the posterior end of the body, identify the median SPINAL CORD, and on each side of it the segmental, paired, muscle plates (MYOTOMES). Ascertain the number in your specimen. Find the AMNION which later completely encloses the embryo, but at this stage covers only the anterior portion of the embryo and ends somewhat posterior to the region where the vitelline vessels enter the body.

3. Study the anterior end of the embryo and locate: (a) the FORE-BRAIN, with the rudiments of the EYE and NOSE; (b) the large, rather spherical MID-BRAIN, and, to the left, (c) the smaller HIND-BRAIN, with a large, dorsal depression (FOURTH VENTRICLE). (d) The rudiment of the right EAR is situated near the posterior end of the hind-brain, and appears as a small, pear-shaped vesicle. (e) The twisted, S-shaped HEART lies outside the body wall in the space between the tip of the head and the curved portion of the trunk. It consists at this stage of (f) a large posterior VENTRICLE, into which (g) the AURICLE opens. A portion of the auricle can be seen to the left. Leading from the ventricle, anteriorly, is (h) the CONUS ARTERIOSUS. It soon divides to form a number of BRANCHIAL VESSELS which run dorsally between (i) the GILL SLITS to form a portion of the aortic arches.

4. Make a full page drawing of the entire embryo to show the structures as observed.

¹ B. pp. 232-238.

DEVELOPMENT OF THE CHICK (2)

1. Place an egg, which has been incubated three days, in a finger-bowl of warm (about 39° C.) normal salt solution. Turn the blunt end of the egg to your right and hold it, fully submerged, with one hand, and, with the other, carefully insert the point of the scissors in the center of the blunt end. Be *very careful* to use only the extreme tips of the scissors in cutting the shell. While holding the egg in the *same position* continue the cut entirely around the egg a little *below* the equator, and then lift off the upper portion of the shell, leaving the rest of the egg, including the lower portion of the shell, with the embryo, immersed in the salt solution.

2. Examine, with the dissecting microscope, the translucent embryo lying on the yolk in the center of the VASCULAR AREA, noting how it is placed with reference to the long axis of the egg. Note the beating HEART, the VITELLINE ARTERIES and VEINS which pass out to the side from the middle of the embryo, and the anterior VITELLINE VEIN which runs under the anterior portion of the embryo. Determine the PULSE RATE. Make a drawing of the entire specimen, with the embryo in place, to show the structures observed.

3. Carefully make a circular cut, with small scissors, through the egg membrane, just outside the limit of the VASCULAR AREA. With fine forceps take hold of an edge of the detached area and very gently separate it and the attached embryo, from the underlying yolk. Hold the detached portion with the forceps below the surface of the liquid, and with the other hand immerse a watch glass in the liquid. Carefully float the embryo into the watch glass, keeping it at all times below the surface of the liquid. Gently raise the watch glass, with the embryo floating in it, and remove entirely from the finger-bowl, taking great care not to lose the embryo. With a pipet draw off a considerable portion of the fluid around the embryo, and replace with a fresh supply of warm salt solution.

4. Examine the embryo with the dissecting microscope, and identify the structures which you previously noted in the permanent preparation of the three-day chick embryo. Under the low power of the compound microscope observe the movement of the red blood corpuscles in the blood vessels. Add warm salt solution from time to time and note the effect upon the pulse rate.

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